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Description of Manganese Nodule Processing Activities for Environmental Studies

Volume II. Transportation and Waste Disposal Systems

August 1977

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U.S. DEPARTMENT OF COMMERCE
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Office of Marine Minerals

Description of Manganese Nodule Processing Activities for Environmental Studies

Volume II. Transportation and Waste Disposal Systems

August 1977

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ABSTRACT: This contract report was prepared for NOAA's Office of Marine Minerals to bring together technological information pertinent to the processing of manganese nodules mined from the sea floor and to help access the effects of manganese nodule processing activities on land and marine environments. It treats potential methods, operations, and requirements for processing and handling manganese nodules on land and at sea, including recovery of value metals, transport of manganese-nodule ore and process wastes, treatment and disposal of wastes, material and energy balances, and resource requirements. The report is available through the U.S. Department of Commerce's National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22151 (telephone: 703-557-4600), in three volumes:

Volume I. Processing Systems Summary
Volume II. Transportation and Waste Disposal Systems
Volume III. Processing Systems Technical Analyses

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EXECUTIVE SUMMARY

Volume II describes the most likely systems for transporting manganese nodules from the mining ship to port and from the port to the process plant. The report also describes waste transport and disposal methods most likely to be used by the industry. The main objective of this study is to delineate the resource requirements (e.g. energy, manpower, land, water, equipment, etc.) needed for each most likely system. This report does not consider the characteristics of nodules or wastes which are of possible concern in evaluating potential environmental effects, except as these characteristics affect resource requirements. The treatment of wastes is assessed in Volume I and such treatment may be necessary to use some waste disposal systems described herein. The transportation and waste disposal systems information contained herein will be combined with processing information contained in Volume I and used in a planned subsequent assessment by the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) of the potential environmental and socio-economic impact of developing a deep ocean mining and processing industry in the United States.

The ocean transportation fleet used to service a mining ship in the near-equitorial North Pacific area of commercial mining interest would probably consist of 55,000 DWT (Panamax size) to 70,000 DWT transport vessels. The smaller vessels would be used for Gulf Coast ports and the larger for Pacific Ocean ports in Southern California or in the Pacific Northwest. The nodules would probably be handled in slurry form to West Coast locations and in dried and ground form to Gulf Coast sites. The number of vessels required would depend on the vessel size, mining rate, distances and whether or not partial at-sea processing was used. For West Coast ports 1 to 3 vessels would probably be used by each operation depending on the mining rate and location of the mining site. Similarly, for the Gulf Coast, 2 to 8 vessels would probably be used. At least two vessels would be in service at all times to insure continuity of the mining operation. An onshore slurry reception facility would occupy approximately 5.2 hectares (13 acres) and a dried-ground facility would occupy approximately 4.4 hectares (11 acres).

Land transportation of nodules to processing plants and the transport of wastes to disposal areas would depend on the physical form of the material. If the nodules are brought to port as a slurry which is most likely for West Coast locations, they would most likely be transported to the process plant in a slurry pipeline. If the nodules are in a bulk form they would be handled by conveyors if the plant is close to port, and by rail if the plant is located some distance from the port facility. If nodules are ground and dried, as might be seriously considered for Gulf Coast locations, either conveyor or rail transportation appears most likely depending on the onshore transportation distance. Unless a requirement to dry wastes before disposal is imposed, the transportation of wastes from the plant to the disposal site would probably be by slurry pipeline.

Three waste disposal systems are identifed as more likely than other options. They include placing dry or nearly dry wastes in a landfill, disposal of slurried wastes in a conventional tailings containment facility, and ocean dumping. The two land disposal techniques would be closed systems; that is, an impermeable lining (or naturally impermeable layer) beneath and cover over the dry wastes or tailings would be used to prevent their release into the environment. Ocean dumping would probably be the most economical system of disposal; however, environmental and legal questions would have to be resolved. Area requirements for land disposal range from 4 hectares (10 acres) per year for dried wastes from four metal (copper, nickel, cobalt, and manganese) plants to 40 hectares (100 acres) per year for slurried waste from three-metal (copper, nickel, and cobalt) plants.

1.0 INTRODUCTION

1.1 DEEP OCEAN MINING IN PERSPECTIVE

Manganese nodules are potato-shaped concretions found on the deep ocean floor in many parts of the world. Although somewhat variable in composition, these nodules may become an important source of nickel, copper, cobalt, and manganese. Manganese nodules can be regarded as a relatively high grade nickel-copper-cobalt oxide ore since nickel, copper and cobalt are the most valuable recoverable constituents of manganese nodules.

While deposits of manganese nodules occur in every major ocean, those in the near-equatorial Pacific are of greatest interest at present because of the greater nodule density in many deposits and their higher than average concentrations of metal values. High concentrations of nodules have been observed over many thousands of square miles of ocean floor and have been estimated to average 10 kg/m^2 (wet weight) (or 2 lb/ft^2) in mineable areas. This is therefore an enormous reserve.

The deposits of greatest commercial interest lie in a belt south of the Hawaiian Islands and north of the Equator and extend almost from Mexico to 180°W (see Figure 1.1). Typically, these deposits lie at depths between 4,000 and 6,000 meters (13,100 and 19,700 feet).

Although the technologies required to locate, mine and process manganese nodules have not yet been demonstrated on a commercial scale, no technological problems are apparent which would preclude development of this resource, given a favorable economic and political climate. Accelerated engineering and development activities over the past decade, with their attendant considerable investment, suggest that initiation of large scale mining could occur as soon as the early 1980s. In addition to possible economic incentives, development of a manganese nodule mining industry in the United States has possible strategic value. The United States is not presently self-sufficient in manganese, nickel, and cobalt. Almost all of our supplies of these metals must be imported from foreign countries; hence our supply and the price we must pay is largely controlled by other nations.

Because of economic and strategic incentives and our leadership in the required technology, the United States will probably be the leader in the development of the manganese nodule deposits found in deep ocean basins. Because of proximity to our shores and high concentration of metal values, the deposits south of Hawaii appear to be the most likely targets, at least for first generations operations. In general, an ocean mining operation will consist of mining vessels, a fleet of

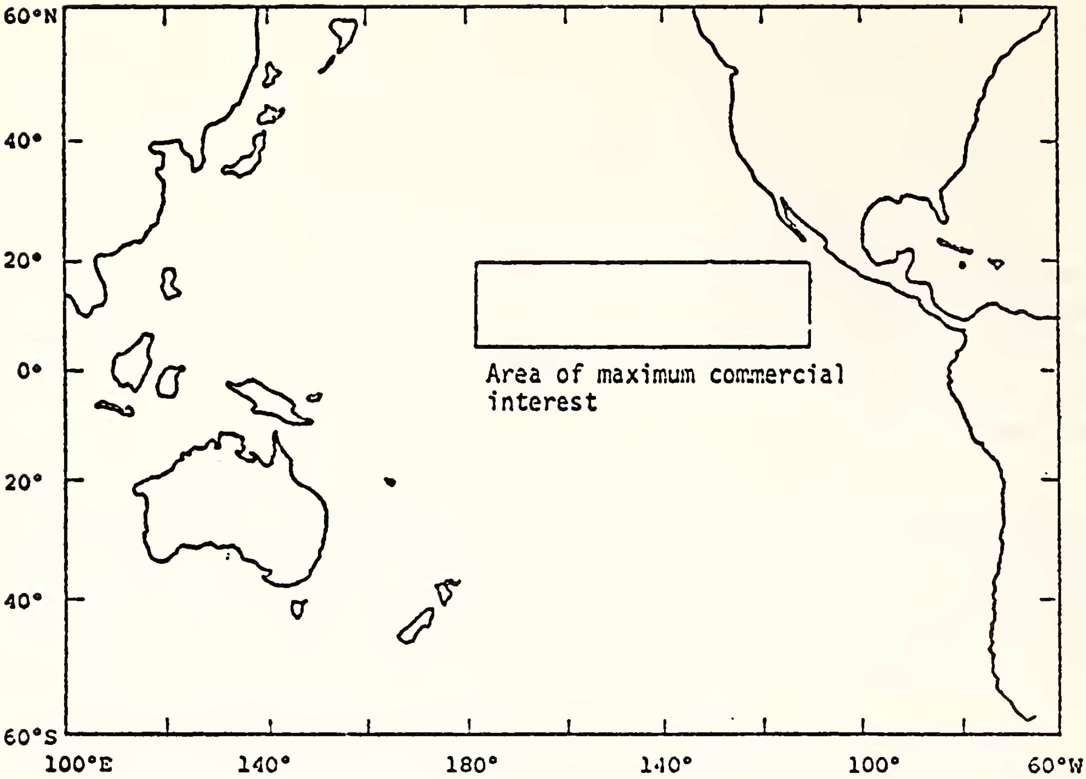

Figure 1-1. NODULE MINING AREA OF MAXIMUM COMMERCIAL INTEREST

carriers which will transport nodules (ore) to a port facility and an on-shore processing plant. There is a possibility that at-sea (shipboard) processing or partial processing may be feasible in the future. However, technical and other problems with at-sea processing will probably lead to use of onshore plants in first generation systems. Since initial nodule mining operations will probably be centered in the belt south of the Hawaiian Islands, the West Coast, Hawaii, or possibly the Gulf Coast may be considered by industry for the siting of port facilities and onshore processing plants. The industry's decisions will be based on total system economics and regulatory considerations in potential areas.

In summary, there appear to be sufficient economic and strategic incentives to develop an ocean mining industry in the United States in the near future. Thus, it is essential to examine both the potential positive and negative environmental and socio-economic effects associated with development of this industry if development is to maximize overall benefit to society. A comprehensive assessment of both positive and negative factors constitutes vital input to the decision making process inherent in establishing a new industry. This assessment will not be easy, since the industry will utilize, in part, new methods and technologies.

A relatively complete knowledge of the methods and technologies to be used by the inudstry must be available to allow analysis of impacts. Opportunities to draw on past experience to develop the required data base are very limited. Thus, the required data must be gleaned from a variety of sources and synthesized into a reasonable characterization of the new industry, recognizing that certain inaccuracies are probable in this approach. A large degree of engineering judgment is required to characterize this potential new industry because of the scarcity of published data. This report identifies and describes the processing facilities which will be needed to recover valued metals from manganese nodules and provides the information needed for impact analyses.

1.2 PURPOSE OF NOAA PROGRAM

It is likely that one or more Federal actions will be associated with development of a deep ocean mining industry in the United States and would be considered a "major Federal action" under the National Environmental Protection Act (NEPA). Thus, it is likely that the Federal Government will be required to prepare one or more environmental impact statements for such an industry to develop. Review of published information dealing with the broad topic of manganese nodules reveals that little or no work has been done, or at least divulged to the general public, on the potential environmental impacts associated with mining, transportation, and processing of manganese nodules. Since this may well become a major industry, both positive and negative environmental effects may be significant. Failure to understand, anticipate, and control or mitigate potential adverse impacts could also lead to delays and add to the total cost of development of the industry. Such work can also aid industry by permitting the design of operations which are environmentally compatible to the maximum practical extent.

As a result, the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) has undertaken two studies to assess the potential impacts of the new industry. The Deep Ocean Mining Environmental Studies (DOMES) Project, already underway, is designed to assess the potential environmental effects of at-sea mining operations in the near-equitorial North Pacific nodule belt and to provide information for the development of appropriate environmental safeguards. In a complementary project the NOAA Office of Marine Minerals has initiated a three-phased program to assess the environmental socio-economic impacts of other activities associated with development of the industry, specifically, ore (nodule) transportation, processing of nodules and disposal of process wastes.

The objective of Phase I of the NOAA Program is to describe and characterize the relevant activites associated with at-sea and land transportation, processing and waste disposal. The Phase I work was performed under two separate, competitively awarded contracts. The first part, the Phase IA Study, was designed to identify and characterize on-shore and off-shore processing methods most likely to be used by the industry. The Phase IA results are summarized in Volume I and details of the technical analyses are provided in Volume III. The second part of Phase I, the Phase IB Study, which is the subject of this Volume, is designed to characterize likely transportation and waste disposal activities. Subsequent phases of the NOAA Program, i.e., Phase II and III, will utilize this data base to analyze and describe the potential environmental and socio-economic impacts associated with the development of the industry.

1.3 PURPOSE OF THIS STUDY

The Phase IB study delineates, in a manner suitable for use in subsequent environmental and socio-economic impact studies, the resource requirements (e.g. energy, manpower, land, water, equipment, etc.) for:

- transporting manganese nodules from an at-sea mining site to shore
- unloading manganese nodules from transport vessels and transporting the nodules to a processing plant
- physically disposing of wastes after value metals have been removed from the nodules.

The nodules can be in a variety of forms as they leave the mining ship (e.g. whole, slurried, or ground and dried) and a variety of options exist for seaborne transport, unloading, port-to-plant transport, and waste disposal. Therefore, it was necessary to identify the major options likely to be considered by industry prior to the preparation of the descriptions of resource requirements. However, it should be noted that the actual methods selected by industry will be highly dependent on the characteristics of the areas proposed for siting, on total system economics, and on relevant regulatory requirements.

It should also be noted that the Phase I work is designed to serve as an input for subsequent impact studies and not to assess potential impacts. In the waste disposal analysis it was assumed that, when necessary and applicable, wastes would be treated prior to disposal in order to permit environmentally compatible use of the method(s). Waste treatment techniques were analyzed as part of the Phase IA Study. Care must also be taken in the interpretation of the Phase I results, since it is unusual to develop this type of information at this stage of industrial development (i.e. without prototypes in operation). Therefore, the results must be viewed in the context of other types of industrial and public operations.

In order to help assess the "realism" and "relevancy" of the work, NOAA requested industry, environmental interest groups, and interested agencies (e.g. the Department of the Interior's Bureau of Mines, the U.S. Environmental Protection Agency, and the Department of Commerce's Maritime Administration) to review the work and to constructively comment on its results. A public briefing was held to receive such comments.

2.0 GENERAL STUDY APPROACH AND ASSUMPTIONS

2.1 PURPOSE

As described previously, the basic purpose of this study is to provide NOAA with resource requirement estimates for likely manganese nodule transportation and waste disposal systems in a manner suitable for subsequent environmental and socio-economic impact studies planned by NOAA.

2.2 STUDY APPROACH

Data developed in the Phase IA study on quantities and types of materials that will be transported, treated and disposed of by a deep ocean mining industry served as the basis for this study. These data were supplemented with assumptions based on literature review and in-house knowledge and experience on planning and design of transportation and waste disposal systems. From this data base, alternative ocean and land transportation and waste disposal methods were identified in accordance with the scenarios provided by NOAA. Once the spectrum of systems available to transport or dispose of the nodules and/or wastes were identified, the most likely systems were selected on the basis of legal and environmental requirements, current usage by similar industries and assessment of the relative economics of technically feasible systems.

The next step in the study was to develop descriptions of the most likely transportation and waste disposal systems in sufficient detail to allow assessment of the impact of these activities. These include a description of physical and mechanical demands and the resource requirements for each system. The energy (fuel or electricity), land, manpower, water and other pertinent data are summarized for each of the most likely transportation and waste disposal systems.

Although the transportation and disposal systems described in this report are commonly used, data relating to their use in the nodule mining industry is non-existent since the first nodule plant has yet to be built. This fact, combined with the unknown location of these facilities dictates that the estimates of the requirements of each system are based in part on assumptions and judgements. Pertinent assumptions are noted in the text. Some data presented in this study is, therefore, general in nature and the actual requirements for a specific system could vary from the data presented in this report. However, the data presented should be indicative of typical requirements for a nodule mining and processing industry and adequate to serve as a base for future NOAA studies.

2.3 STUDY PARAMETERS

The parameters (e.g. quantities of materials, forms of materials, and distances) used in this study were based on information developed in the Phase IA Study, scenarios prescribed by NOAA, literature reviews, and in-house expertise and experience. Much of this information is common to all parts of the Phase IB Study and is summarized in the following paragraphs.

2.3.1 Scenarios Prescribed by NOAA

For the ocean transportation portion of the study NOAA required that the following scenarios be considered.

1) Hauling manganese nodules in three forms - slurry, whole (as mined) and dried and ground

2) Two mining sites - Site B from DOMES study and western extremity of probable mining area

3) Three port areas - Pacific Northwest, Southern California and Central Texas

NOAA excluded Hawaii from the seaborne transportation section because of the specialized type of analysis which would be required for a Hawaii-based processing operation.

The following scenarios were provided for land transportation:

1) Process plant location - adjacent to port and 8 or more kilometers (5 or more miles) from the port.

2) Disposal sites - distances chosen in accordance with their effect on transportation type.

NOAA specified that six waste disposal methods be addressed in this study. The methods were specified without a predetermination that any was more desirable or more acceptable than any other, since the purpose is to describe the characteristics of each type of operation. The methods reviewed are:

1) Spread over a land disposal area (e.g. either as piles or in layers) when the area is adjacent to the plant and at three different distances from the plant.

2) Burial in a landfill (i.e. alternating layers of wastes and cover material) when the landfill is adjacent to the plant and at three different distances from the plant.

3) Use as cover material in a municipal sanitary landfill when the landfill is at three different distances from the plant (including an estimate of how much landfill area would be covered per month).

4) Use of holding ponds for the evaporation of the liquid component when the ponds are adjacent to the plant and at a distance of 8 kilometers (5 miles) or more from the plant (including conventional tailings disposal methods).

5) Storage adjacent to the plant as a manganese reserve for further processing in the future.

6) Open ocean dumping when the plant is located adjacent to the port and when the plant is located 8 kilometers (5 miles) or more inland from the port (including an evaluation, in broad terms, of using empty ore carriers for the dumping as opposed to using specialized barges).

NOAA also required consideration of mining rates for both 3-metal and 4-metal scale operations. These rates are specified in the next section.

2.3.2 Data from Phase IA Study

Essentially all of the process specific information used in this study was taken from the Phase IA Study. The physical characteristics and weights and volumes of incoming nodules and outgoing wastes are summarized below.

1) Annual mining rates:

	Tonnes per year	Tons per year
- 3-metal plant		
wet (as mined)	3.7×10^6	4.1×10^6
dry	2.2×10^6	2.5×10^6
- 4-metal plant		
wet	1.1×10^6	1.25×10^6
dry	0.7×10^6	0.75×10^6

- Assuming 40% water and 60% solids
  water - 10% water of hydration
  5% surface water
  25% interstitial water

2) Physical characteristics

- apparent specific gravity of whole nodule 2.0
- average specific gravity of nodule constitutents 3.2

3) Annual waste production:

	Tonnes per year	Tons per year
- 3-metal plant		
solids	3.7×10^6	4.1×10^6
liquids	4.5×10^6	4.9×10^6
- 4-metal plant		
solids	0.62×10^6	0.69×10^6
liquids	0.63×10^6	0.70×10^6

(Note: there is considerable variance between different 3- and 4-metal processes. In general higher rates were chosen.)

Specific data required for specific modes of transportation or waste disposals are summarized in the text in the appropriate location.

3.0 AT SEA TRANSPORTATION AND PORT REQUIREMENTS

Transportation of manganese nodules from the mining site to seaports can be accomplished with conventional ships or vessels specially designed for the cargo form and density and for the cargo handling methods deemed most desirable for a specific mining-processing operation. Presently large tonnages of iron ore and pellets, bauxite, coal, phosphate, grains, and similar dry bulk commodities are carried by both the few United States ships and thousands of foreign ships into and out of American ports. Slurry, dry bulk and pneumatic handling methods are all in use.

Estimated world seaborne trade in 1976 included 290 million long tons* of iron ore, 122 million long tons of coal, 140 million long tons of grains, and over 150 million long tons of phosphate, bauxite, manganese, sugar, coke, gypsum, salt, sulfur, and non-ferrous ores.

North American dry bulk ocean shipments exceeded 235 million long tons and imports exceeded 72 million long tons in 1975 and carried by bulk ships over 18,000 DWT. Smaller ships and other carriers carried additional tonnages, particularly of grains and coal. The U.S. imported by ocean ship about 35 million long tons of iron ore, and exported about 56 million long tons of coal, mostly to Japan. About 83 million long ton of grain were also exported, 10 million long tons of phosphate rock, 5 million long ton of manganese ore, and 5 million long ton of gypsum were imported. The impact of transporting 1 to 4 million long tons of nodules per plant per year would be negligible by comparison.

The principal unusual feature of manganese nodule transport is the at-sea loading from the mining ship to the transport vessel. This transfer can be accomplished by existing methods, including conveying, slurry pumping, and pneumatic blowing. Also, the density of the nodules which is similar to iron ore requires that ships be specially designed or strengthened to carry the nodules, for all handling methods. Ore carrier configuration, or combination ship design, is appropriate. Presently ore carriers, and combination bulk, ore, or oil ships, are in service for shipment of petroleum, dense ores, and ordinary dry bulk commodities (Swan, 1974).

The return of fuels and supplies from shore to the mining ship is also expected, and therefore a combination oil and ore ship design is most likely. For slurry cargo handling or self-unloading, special equipment may be installed in the transport ship. Fuel oil pumps are installed on every ship. The provision of appropriate ship transport service for nodule mining is easily within the current state-of-the-art for several methods that are widely available.

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*For purposes of this study long tons are equivalent to tonnes and dual metric/English will not be used in these cases.

3.1 MINING SHIP

3.1.1 Physical Characteristics of Nodules Aboard the Mining Ship

Transportation of nodules to shore may be performed with the nodules in their raw state or after grinding sufficiently to prepare a pumpable slurry. Drying of ground nodules is also considered possible in certain cases discussed later.

The whole nodules as mined and raised have an apparent density of approximately 2 grams per cubic centimeter (125 pounds per cubic foot), including entrapped capillary and bound water. The mining and raising is reported to smooth the nodule surface, but not cause extensive breakage, so that 90 percent of the nodules are essentially as found on the seabed. The abrasion produces fines which may be separated along with bottom sediment and returned to sea from the mining ship(s).

Nodules reportedly have a porosity ranging between 45 and 60 percent. The true specific gravity of nodule material is about 3.2. To increase the density, grinding would be needed to reduce particle sizes, and hence porosity, of the nodules. A reasonable grind (100 percent passing a #10 sieve, i.e., less than 1.68 mm) would result in a slurry specific gravity of about 1.6 when mixed with water. This produces a pumpable slurry that can be maintained by air agitation. In addition to grinding, the nodules may also be dried at low temperature 110°C (230°F), which would reduce total weight by about 30 percent. Considerable energy would be required to dry the ground nodules. Handling of the dried ground nodules would be relatively difficult, particularly compared to slurry methods. However, savings in transportation cost makes drying economically attractive if the distance to the port is large.

3.1.2 Nodule Stowage

The nodule stowage factor onboard ship is about 0.5 to 0.7 cubic meters per tonnes (18 to 25 cubic feet per long ton). This is relatively dense and therefore would require use of ore-carriers which are designed to handle dense cargoes with a specific gravities greater than about 1.5.

The volume of stowage required on the mining ship depends upon the mining rate and the frequency of transport ship carriage of nodules to shore. For a 3-metal process, 3.7 x 10^6 tonnes per year (4.1 x 10^6 tons per year) of nodules would be mined. Therefore, the mining ship's stowage for one day's operations would be 11,200 long tons. For a 4-metal process 1.1 x 10^6 tonnes/year (1.25 x 10^6 tons per year) of nodules would be mined. Therefore one day's stowage would be 3400 long tons. As a dewatered slurry, 11,200 long tons of wet nodules would require a hold 36 meters long by 12.2 meters deep by 18.3 meters wide (103 feet long by 40 feet deep by 60 feet wide) plus ullage. The same hold would stow slightly more than three day's worth of nodules at the lower mining rate. Similar spaces would be needed for unprocessed and for ground nodules. This is a reasonable size compartment for a mining ship. Three to six such holds would be needed to assure continuity of mining at a 3-metal production rate, in case transport ships are not able to stay on schedule. The stowage capacity of two such compartments would provide adequate mining ship stowage in a 4-metal operation.

3.1.3 Transport Ship Loading At Sea

The nodule transport ship could be designed for carriage of slurry, whole nodules, or dried and ground nodules. Available reports indicate slurry methods are most promising and are under consideration by all consortia. The possibility exists, at least in first generation operations, that transport of raw nodules or dry ground nodules to shore would also be utilized. Methods of handling nodules in each of these possible forms is discussed below, with priyary emphasis on the slurry system (Kirshenbaum, 1974).

3.1.3.1 Slurry Handling

The slurry would consist of ground nodules in salt water, about 40 percent nodules by weight. Water jets directed into the material stowed on the mining vessel would slurry the ore which then flows to a collecting sump under the stowage tank. Seawater is added as needed for the proper mix, and pumps discharge the slurry at main deck level into pipelines or flexible hoses to the transport ship.

To prepare large nodules for slurry pumping, a cage mill and a rod mill may be required. The cage mill and the rod mill each are about 3.7 meters (12 feet) in diameter by 7.6 meters (25 feet) long. Nodule crushing would probably be continuous with the mining operation, rather than performed at ship loading time. Reduced abrasion of pipe linings and reduced pumping power requirements would result from the smaller particle size of crushed nodules. Also, dewatering in the mining and transport ship cargo holds may be easier with smaller particles.

Slurry handling systems can be of closed loop design, where the salt water of the slurry is recycled back to the unloading ship from the decanted water of the discharged cargo. In an open loop, new sea water is used to form slurry. Discharge of fines is minimized with a closed loop slurry system.

Slurry cargo holds would be hopper-shaped, with smooth sides, to expedite cargo removal. Dewatering is accomplished mostly at the bottom of the hold. However, some decanting at the top of the hold is likely. Dewatering improves cargo stability and slows any tendency to cargo shifting. Slurried nodules probably would contain less than 10 percent of the transport water by weight within a few hours of loading.

Slurry pumps have a capacity of about 500 long tons per hour per hold. One pump would probably be installed permanently in each hold. Five to six slurry transfer pumps per transport ship to unload slurry are anticipated for the ship sizes under consideration. Multiple slurry pumps having a total capacity of several thousand long tons per hour would be required to transfer slurry from the mining ship to the transport vessel in an acceptable period of time, i.e., less than one day. The at-sea slurry tanker loading scheme is illustrated in an artist's conception on Figure 3.1 (Marconaflo, Inc., 1976).

3.1.3.2 Whole Nodules

Intact nodules could be pumped into a cargo hold on the dry bulk ore transport ship and dewatered. Removal of free water is essential to avoid impairing vessel stability. These nodules would likely be moved by belt or screw conveyors or handled by conventional clamshell buckets. However, some reports indicate that nodules tend to disintegrate when any of these operations are performed, or when nodules are stacked in large piles or in a ship hold. This will no doubt be investigated in detail prior to selecting any of these handling systems.

To transfer raw nodules to a transport dry bulk ore ship, conveyors would be necessary. The nodules are reported to be too large and heavy for pneumatic transport or for slurry pumping without grinding, and too small for efficient bucket handling. Clamshell handling and transfer at sea is also too slow and awkward, requires a large deck area, and requires that the transport ship come alongside the mining ship. The latter operation presents risk of collision, and could not be continued in bad seas or weather.

Even conveyors to another ship alongside have problems in accurately loading directly into transport ship holds. A receiving hopper and distribution conveyor on the transport ship may be required. The receiving hopper could be fitted at the bow, and loaded from the mining ship's stern conveyor extended aft on a long boom.

Conveyor emptying of both mining and transport ship holds can be performed at relatively high rates. One conventional conveyor could serve several holds at discharge rates of a few thousand long tons per hour. Because of the ship motions at sea, the conveyor would have to be enclosed to prevent loss of cargo, and also to prevent spilled fines from clogging shipboard machinery.

If the system is designed so that the transport ship accompanies the mining ship to accept nodules as mined, the number or size of transport ships will be larger, hence this sytem is not considered likely.

3.1.3.3 Dried and Ground Nodules

The manganese nodules could be dried at 110°C (230°F) for elimination of both surface water and most of the capillary water. This would remove approximately 30 percent of the gross weight of the cargo which must be transported to shore. The installation of cage mills and fluid bed dryers, with assorted precipitators for dust control, would be necessary on the mining ship. The dry nodule particles, with lower

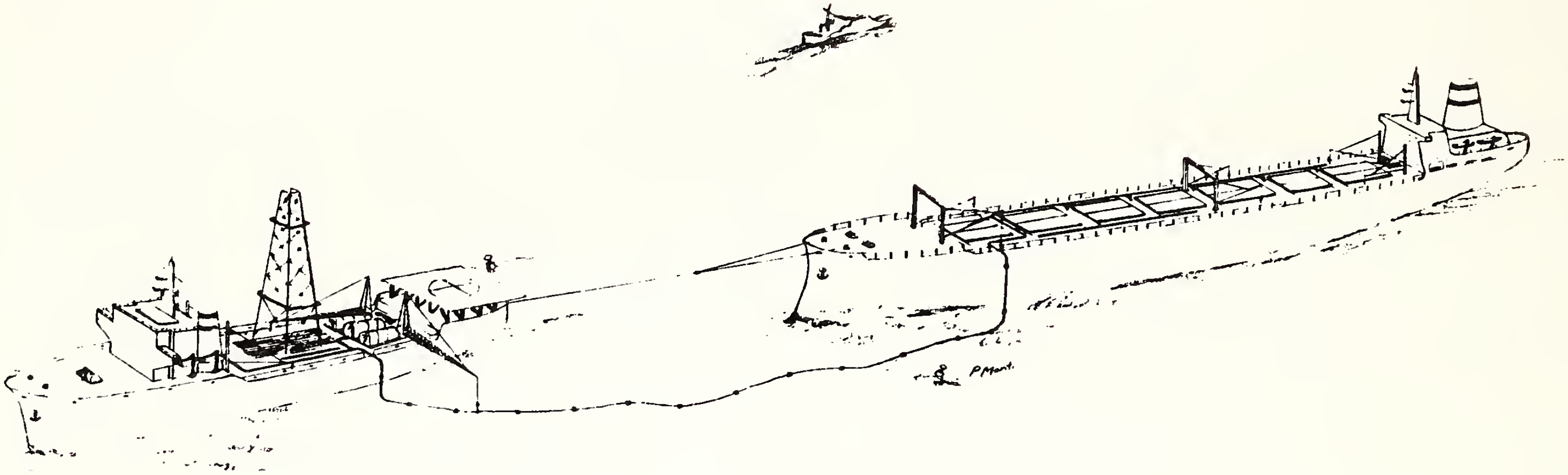

Figure 3.1: Transfer At Sea of Slurry From Mining Ship To Transport Ship

density, could be conveyed to a stowage hold of about the same dimensions as discussed above. A dry bulk conveyor or screw handling system would be installed, rather than slurry jets and pumps.

Dry nodule material is reported to be quite friable and tends to disintegrate into dust size particles. Dust from dry nodule handling could become a substantial problem. Dried and ground nodules would most likely be handled by vacuum devices similar to those for grains. Pneumatic conveying at sea is more difficult and much slower than slurry pumping. Discharge times would be at least twice those required for slurry pumping. Also, the humid climate aboard ship will tend to cake fine grained dried materials which produces difficult to handle lumps. Exceptionally dry conditions would be necessary for all stages of handling and stowage. However, installation of the size-reduction and drying apparatus on the mining ship may be an alternative to placing the equipment at onshore based plants or at the marine terminal.

3.2 AT-SEA TRANSPORTATION

The at-sea mining site locations and port areas for marine terminals were specified by NOAA and are described in Section 2.0. The nodule transportation described below is based upon these location assumptions, and both the high, three-metal and low, four-metal mining and plant production rates.

3.2.1 Shipping Routes

The area where known nodule concentrations are highest and hence mining is most likely to occur is about 6400 kilometers (about 4000 miles) long and 1290 kilometers (800 miles) wide. The coordinates are given in Table 3.1. Thus, the distances from mining sites to the U.S. mainland or to Hawaii can vary greatly. The maximum diameter of the most likely mining site was assumed for this analysis to be 560 kilometers (350 miles) or about one day's sailing time for modern bulk ships which steam at 28 to 30 kilometers/hour (15 to 16 knots).

TABLE 3.1

AREA OF COMMERCIAL INTEREST

Location	Latitude	Longitude
Eastern Boundary	5° to 17°N	110°W
DOMES Study Site B	11°42'N	138°24'W
Western Boundary	5° to 19°N	180°W

For purposes of this study, DOMES Study Site B and the middle of the Western Boundary are assumed as mining sites.

Three general United States Coastal areas were specified by NOAA as being possible, or representative, areas for discharge of incoming nodules. These are the Pacific Northwest (near the mouth of the Columbia River was used for the distance computation), Southern California, and Central Texas in the Gulf of Mexico. The distances from these ports to the sites are shown in Table 3.2.

TABLE 3.2

PORT TO MINING SITE DISTANCES

	Distance to Site B		Distance to Western Boundary	
	kilometers	(nautical miles)	kilometers	(nautical miles)
Pacific Northwest	4,220	2,270	6,950	3,750
Southern California	3,240	1,750	6,180	3,850
Texas via Panama Canal	9,140	4,930	12,880	6,950

Each mining ship would probably operate in a relatively restricted area. Hence, variation in distance to port would not likely be large for a given mining operation.

3.2.2 United States Ports

The United States destination port areas all have navigation channels with limited water depths, thus limiting the size of the entering nodule transport ship. Specific channels are listed in Table 3.3 for each area for the possible nodule marine terminal.

3.2.3 Transport Vessels

Because of the high density of the manganese nodules, an ore-carrying type ship with reduced hold width and higher hold center of gravity is needed for proper stability. Whether slurry or dry form, the ore-carrying configuration is essential. In addition, transport of fuels, supplies and wastes would probably be necessary. Therefore a combination of ore-oil vessel, or a universal bulk carrier, would be required.

The slurry ship is basically an ore-oil ship with the water jets and discharge pumps installed in the lower void under the cargo holds, and additional piping installed for slurry loading, sea water handling, and dewatering and decanting of the slurry holds.

Ship dimensions are presented in Table 3.4 as a function of ship size as measured by deadweight tonnage (DWT). Dimensions given are typical of vessels that tend toward shorter length and shallower draft, which are representative of recent designs and new construction. Actual dimensions can vary by several feet from those in Table 3.4 (Rosenblatt, 1976).

TABLE 3.3

PRINCIPAL NAVIGATION CHANNELS

Location	Minimum Depth		Channel Width		Channel Length	
	meters	(feet)	meters	(feet)	kilometers	(nautical miles)
Columbia River						
Entrance	14.6	48 S.W.			22	12
Longview	10.7	35 F.W.			85	46
Bonneville	5.2	17 F.W.			126	68
Texas						
Entrance	13.4	44 S.W.			9.3	5
Galveston Harbor	12.8	42 S.W.			7.4	4
Houston Ship Channel	12.2	40 F.W.	122	400	89	48
Bayport	11.0	36 S.W.	91.5	300		
Port Arthur, Texas	12.2	40 S.W.	153	500		
Freeport, Texas	9.8	32 S.W.			15.9	8.6
Corpus Cristi, Texas	12.2	40 S.W.				
Texas City	11.0	36 S.W.			13	7
Southern California						
San Diego	12.2/10.4	40/34 S.W.	244	800	11/20	6/11
Long Beach-Outer	18.3	60 S.W.	214	700	13.9	7.5
Inner	14.3	47 S.W.	107	350	4.6	2.5
Los Angeles-Outer	15.6	51 S.W.	153	500	2.8	1.5
Inner	10.7	35 S.W.	122/183	400/600	9.3	5
Panama Canal	11.7	38.5 F.W.	34	110	82	44

Notes

S.W. = Salt Water

F.W. = Fresh Water

Source: U.S. Coast Pilots

A 55,000 DWT ship with beam less than 32 meters (105 feet) and draft in fresh water less than 11.9 meters (39 feet) is about the largest able to transit the Panama Canal, i.e., "Panamax" size. Bulk carriers designed especially for maximum cargo loads through the Panama Canal are longer and narrower than typical designs. When not limited by Canal draft restrictions, they can carry even larger cargoes.

Generally the water depths available inside harbors is about 12.2 meters (40 feet) in salt water at low tide (see Table 3.3). Allowing for tidal rise and deeper dredging at berths, about 12.2 meters (40 feet) draft ships would be the maximum size that could be fully laden and still transit most harbors. These are equivalent to about 65,000 DWT or less as shown on Table 3.4 (Corps of Engineers, 1973).

3.2.4 Likely Transport Vessel Fleet

The vessels for transportation of nodules from mining ship to shore, whether they are ships or tugs and barges, can be described only in generalities until the specific features of the port and handling system are delineated.

3.2.4.1 Likely Fleet - Nodule Slurry Only

For purposes of initial estimation, the approximate vessel fleet requirements were computed assuming:

- Cargoes are handled in slurry at 4,500 long tons per hour for all size ships, both at sea and in port.

- A delay time of 6 hours per one-way voyage, and no extra sailing distance is required.

- All vessels operate only during the 330 days per annum that the mining ship operates.

- Cargo capacity is 90 percent of deadweight tonnage for ships on the Pacific Ocean, and 80 percent for the ships transiting the Panama Canal.

- The largest ship able to transit the Panama Canal loaded is about 55,000 DWT at transit draft.

- "Adequate" nodule stowage and handling equipment is provided on on the mining ship to transfer cargo at the rate described for each method.

- 3.7 million tonnes (4.1 million tons) of nodules are mined annually at the site for a 3-metal plant and 1.1 million tonnes (1.25 million tons) for a 4-metal plant.

- Ships are chartered full time to maintain a regular schedule.

TABLE 3.4

TYPICAL COMBINATION SHIP DIMENSIONS

DWT	Length B.P.		Beam		Depth		Draft S.W.	
(Long tons)	(meters)	(feet)	(meters)	(feet)	(meters)	(feet)	(meters)	(feet)
15,000	146	480	20.4	67	11.1	36.5	8.4	27.5
20,000	163	535	23.2	76	12.7	41.5	9.2	30.0
30,000	186	610	26.8	88	14.6	48.0	10.2	33.5
40,000	203	665	29.6	97	15.7	51.5	11.0	36.0
50,000	217	710	31.7	104	16.8	55.0	11.6	38.0
60,000	220	720	33.6	110	17.7	58.0	12.0	39.5
70,000	226	740	36.9	121	18.6	61.0	12.5	41.0
80,000	233	765	39.6	130	19.4	63.5	12.8	42.0
100,000	247	810	42.1	138	20.6	67.5	13.3	43.5

Notes

DWT = Deadweight tonnage in long tons, the total weight capacity for fuel, supplies and cargo.

Length B.P. - Length between perpendiculars (approximately at the waterline)

S.W. = Salt water

Beam and Depth are molded dimensions inside steel plating.

- At least two transport ships are provided in the system to minimize vulnerability to total stoppage.

Table 3.5 summarizes the characteristics of the appropriate ships for transportation of 3.7 million tonnes (4.1 million tons) of nodules from the mining site to port, and perhaps return of fuel oil and small supplies to the mining ship. If barges are used, about twice as many would be needed because of their slower sea speed. If the transport ship must stay alongside to accept nodules as mined at less than 1000 long tons per hour, rather than transferring rapidly at 4500 long tons per hour, a larger size or number of ships or both would be required to make up for the delay.

TABLE 3.5

LIKELY FLEET - NODULES SLURRY

(3-Metal Plant)

Site B to:	Southern California		Pacific Northwest		Central Texas
Numbers Ships	2	3	2	3	8
DWT each	63,000	44,000	87,000	58,500	55,000
Arrival Interval, (Days)	5.4	3.8	7.2	4.8	4.0
U.S. Vessels Cost, (Million $)	69.6	84.0	80.4	94.5	227

If U.S. ships are utilized for the transport service, probably the largest vessels would be constructed in the U.S. and manned by Americans. For foreign flag ships with lower costs, the next smaller vessels may be selected, to minimize total system costs and initial investment (Maritime Administration, 1972).

Clearly the 925 kilometers (500 nautical miles) added voyage length to the Pacific Northwest adds substantial cost to the transport system. Vessels with capacity about one-third larger are required, and the extra size of the largest ship would be too large for the harbors. Therefore three vessels are required, rather than two for Southern California, which increases costs approximately 35 percent.

For the Texas site, eight of the largest ships able to transit the Panama Canal would be required for a three-metal plant. The investment cost in the larger number of small ships is about three times the average investment in ships for service in the Pacific Ocean only.

The vessel size limitation of the Panama Canal seriously increases transportation costs to a Central Texas processing site. In addition to canal tolls, longer voyages with irregular voyage times will complicate operation scheduling. The initial investment alone is about one hundred thirty seven million dollars more. With interest on the ship mortgages of almost an equal amount, the system cost would be raised almost four dollars per ton of nodules mined over the project life.

Most major U.S. ports can take all the ship sizes listed on Table 3.5, up to about 65,000 DWT of typical designs, at high tide in the outer harbors. Mono-mooring buoys located in 12.2 to 15.5 meters (40 to 50 feet) of water could be used as terminals. The largest ship shown, 87,000 DWT, probably could not be readily accommodated in U.S. ports because its draft is almost 13.1 meters (43 feet).

The minimum channel depths of 10.7 meters (35 feet) at low water with no tide in secondary ports and channels limits ship size to about 25,000 DWT. At this small size limitation on ships, the large number of ships required (four to seven for Pacific Coast processing sites) would lead U.S. operators to evaluate tug and barge combinations that move under tow at about half of ship speed. For each tug underway and pulling a loaded barge, another barge would be discharging its load of nodules. Thus Southern California service would include 8 tug boats of almost 8000 horsepower each, and 9 barges of 28,000 DWT. Each tug would make a round trip to Mining Site B in 21 days, including refueling. Use of shallow ports and multiple tugs and barges is not considered likely (Smith, 1971).

The likely fleets for the smaller capacity four-metal plants are shown in Table 3.6. These plants would require transport of only about 30 percent of the tonnage required to support a three-metal plant.

TABLE 3.6

LIKELY FLEET - NODULES SLURRY

(4-Metal Plant)

Site B to:	Southern California		Pacific Northwest		Central Texas
Number Ships	1	2	1	2	2
DWT each	43,000	22,000	56,000	30,000	55,000
Arrival Interval, (Days)	11.2	5.3	14.5	6.0	16
U.S. Vessels Cost, (Million $)	28.4	44	32.8	50.2	65

The lower traffic volume will not result in proportionately lower transport vessel size and costs, because of the economies of scale.

For the four-metal plant, two Panamax ships may be adequate to meet the lower volume transport requirement to Texas ports. However, mining ship towage of about 60,000 long tons of nodules would be necessary because of the infrequent ship calls and the 32 day round trip, as compared to 11 to 15 day voyages to the Pacific Coast ports.

3.2.4.2 Likely Fleet - Nodule Slurry and Tailings Waste Slurry

If slurry handling ships are also used for ocean disposal of tailings as well as fuel backhauls; larger ships, by approximately 10 percent would be required for the extra weight of the outbound cargo. Another change would be the extension of port time for loading outbound cargo for disposal at sea. An extra 10 to 15 hours ship port time would be needed as a minimum, and probably more, for tank cleaning and equipment preparation (Hall, 1974).

Table 3.7 shows the required ship size computed on the same basis as before, except for addition of the outhaul of waste tailing slurry, which would be pumped overboard by ship's equipment while underway at reduced speed in deep water enroute to the mining site. This obviously assumes that discharge of wastes at sea is allowable.

The largest ship, 104,500 DWT with a draft of about 13.7 meters (45 feet) exceeds the present depth limitations of the Columbia River entrance and therefore at least three smaller ships would have to be utilized for this service. The waste back-haul would increase ship investment and operating costs about 5 to 15 percent.

TABLE 3.7

LIKELY FLEET

NODULES SLURRY AND TAILINGS SLURRY - 3-METAL PLANT

Site B to:	Southern California		Pacific Northwest		Central Texas
Number ships	2	3	2	3	8
DWT each	74,000	49,500	104,500	62,300	55,000
Arrival Interval (Days)	6.0	4.0	8.5	6.5	4.0
U.S. Vessels Cost, (Million $)	74.6	93.0	88.0	103.2	260.0

The waste tailings would presumably be pumped aboard as a slurry from terminal pumps located ashore. A high transfer rate of 4500 long tons per hour for this loading would require an extensive marine terminal, including installation of waste tailings ponds with large capacity. The liquid for slurry transport would be recycled from the transport ship holds while the cargo is dewatered during loading. Additional water removal may take place after loading is complete. This liquid would be disposed overboard in the harbor or at sea as soon as possible to lighten the load and improve stability. If this overboard discharge is not possible because of contaminants in the slurry transport water, then a longer port time would be needed to pump the dewater ashore before ship departure. This in turn would require larger ships in order to make up for lost time.

Discharge at sea may be accomplished with the nodule pumps connected to an overboard discharge line. Surface discharge through standard outlets could easily be provided. If subsurface discharge is desired to reduce surface plume effects, an on-deck system of pipes, joints and handling methods would be necessary. A shipboard, deck-mounted crane would be needed to lift pipe lengths into place and hold them while joint connections are made. Winches would hold the units hanging over the ship quarters, while pumping overboard and underway. If more than a few hundred feet of overboard discharge pipe is needed, the equipment handling could become a sizeable operation. Also, a long and large pipe dragging astern would slow the vessel. In fact, the vessel probably would be slowed deliberately to reduce the stress in the pipe. Assuming a pumping rate of 4500 long tons per hour, and the ship slowing to half speed, 13.9 kilometers/hour (7.5 knots), about 325 tonnes of waste per kilometer (600 long tons per nautical mile) would be deposited. At this rate, waste pumping would require about half a day and cover 150-167 kilometers (80-90 nautical miles).

Both methods of at-sea discharge would require special vessel equipment which would add to conventional ship cost. The equipment expense for subsurface discharging would be on the order of a few million dollars per ship, and probably require much maintenance effort and additional crew wages for overtime and cargo handling.

Table 3.8 shows the fleet requirements for four-metal plants to handle both slurry nodules and wastes.

TABLE 3.8

LIKELY FLEET

NODULES SLURRY AND TAILINGS SLURRY - 4-METAL PLANT

Site B to:	Southern California		Pacific Northwest		Central Texas	
Number	1	2	1	2	2.4	3
DWT each	51,000	24,000	63,000	31,000	55,000	45,000
Arrival Interval (Days)	12.0	5.5	15.3	7.1	Varies	10.6
U.S. Vessels Cost (Million $)	30.4	45.8	34.6	51.0	---	89.7

For a four-metal plant located in Central Texas, the number of Panamax vessels would be 2.4 to meet the nodule transport requirement of 1.1 million tonnes (1.25 million wet tons) and 590,000 tonnes (650,000 tons) of waste annually. Commercially the larger vessels are more practical and would be placed on charter to others for a few voyages each year. If three smaller ships of 45,000 DWT were utilized full time, ship arrivals would be at intervals of over 10 days. Hence, the mining ship would need stowage exceeding 36,000 long tons of wet nodules.

3.2.4.3 Likely Fleet - Unprocessed (Raw) Nodules

The transport of dewatered nodules as mined could be accomplished by a conventional ore-carrier or combination ship without any cargo handling equipment. The mining ship would provide a loading conveyance of the appropriate kind, and conventional shore terminals described in Section 3.3.2 would discharge the carrier. The cargo handling time under even the best circumstances would be on the order of one-third to one-half day longer than for slurry systems. Since fewer voyages could be made by the transport ship, the size of each vessel would again be slightly larger than for the nodule slurry carrier.

The estimates in Table 3.9 assume loading rates of 5,000 long tons per hour and discharge rates of 3,000 long tons per hour. These are the best that can be expected under ideal circumstances and with generous investment in loading and unloading facilities. However, more realistic transfer rates are about half of the slurry system rate, or about 2,800 long tons per hour (average of loading and unloading rates). If the nodule mining ship transfers at about 500 long tons per hour for continuous alongside transport ship loading, then much larger ships, or more ships, or both would be necessary.

TABLE 3.9

LIKELY FLEET - UNPROCESSED NODULES - 3-METAL PLANT

Site B to:	Southern California		Pacific Northwest		Central Texas
Number Ships	2	3	2	3	8
DWT each	73,000	47,000	92,400	61,600	55,000
Arrival Intervals (Days)	5.9	3.8	7.6	5.1	4.0
U.S. Vessels Costs (Million $)	74.0	91.2	82.8	102.6	260.0

The size of the dry ore ships are so large (73,000 to 92,400 DWT) that the option of three smaller vessels would probably be selected for all Pacific Coast processing sites. The slower cargo handling compared to slurry nodule pumping requires larger ships up to the limits of practical size, or more ships which cost more money to build and operate.

If a slower cargo transfer of 2800 long tons per hour is assumed, then three ships of about 55,000 DWT would be needed for the Southern California run, and three of 70,000 DWT (the maximum size acceptable at Columbia River) would be needed for the Pacific Northwest run.

Table 3.10 presents the results of the same computations for the smaller nodule mining rate appropriate for a four-metal plant.

TABLE 3.10

LIKELY FLEET - UNPROCESSED NODULES - 4-METAL PLANT

Site B to:	Southern California		Pacific Northwest		Central Texas
Number Ships	1	2	1	2	3
DWT each	48,000	23,000	56,500	30,000	49,000
Arrival Interval (Days)	11.6	7.5	14.8	7.1	11.9
U.S. Vessel Cost (Million $)	30.9	45.0	32.9	50.2	93

For the Central Texas route with the lower traffic volume for a four-metal plant, three ships of 49,000 DWT would serve with rapid (4,000 long tons per hour average) cargo handling. For probable transfer rates (2,800 tons per hour) the three ships would all be Panamax size and normally operated in a full-laden transit condition.

3.2.4.4 Likely Fleet - Dried And Ground Nodule Material

The dried nodules would be expected to be quite friable and be expected to be dusty. Pneumatic discharge and load equipment could be expected to transfer about 1,500 long tons per hour under normal circumstances, about one-third the transfer rate of the slurry method. However, in a dried condition, almost 30 percent of the weight of nodules will be removed, so that a valuable advantage is obtained, unless wet waste tailings are to be returned to sea.

The tabulated vessel sizes shown in Table 3.11 for the three-metal plant indicate that the 30 percent reduction in nodule weight would require much smaller ships, even with the slowest pneumatic handling rate. This significantly reduces the direct ship investment cost, since a less expensive dry ore-carrier only design is required.

The dry ore-carrier costs are about 4 percent less than combination ships which would also be capable of transporting large amounts of fuel oil to the mining ship.

TABLE 3.11

LIKELY FLEET - DRIED MATERIAL ONLY - 3-METAL PLANT

Site B to:	Southern California		Pacific Northwest		Central Texas
Number Ships	2	3	2	3	6
DWT each	56,000	32,500	71,500	44,000	55,000
Arrival Interval (Days)	6.6	3.8	8.4	5.7	5.0
U.S. Ship Cost (Million $)	63.2	74.9	70.8	85.3	250.0

Table 3.12 shows the ships for alternatives plant locations which could handle the four-metal plant transportation of dried nodules.

TABLE 3.12

LIKELY FLEET, DRIED MATERIAL ONLY - 4-METAL PLANT

Site B to:	Southern California	Pacific Northwest	Central Texas
Number Ships	1	1	2
DWT each	36,500	46,500	48,500
Arrival Interval (Days)	12.4	15.9	31.3
U.S. Ship Cost (Million $)	26.2	29.1	59.1

If all ore for the four-metal plant is dried prior to transport from the mine site, only 773,000 long tons of dry material needs to be shipped annually. This can be handled by only two Panamax ships, however they would have some excess capacity. This vessel requirement is the same as for slurry ships which do not carry waste tailings outbound, because the lower tonnage nearly offsets the longer time estimated for dry nodule material handling.

3.3 PORT FACILITIES

Facilities for receipt of inbound nodules, nodule storage, and the start of inland transportation would be needed. Terminals could be designed for handling of nodules in slurry, whole, or dried and ground forms. This section describes requirements for terminals of each type.

3.3.1 Slurry Terminals

3.3.1.1 On-Shore Terminals

Slurry terminals in deep water harbors are generally comparable to tanker terminals. Essential elements of this type of nodule terminal would include the dock, mooring dolphins, pipeline connections, an access trestle and pier, a shore receiving pond, and a pumping station. A typical terminal layout for an onshore slurry terminal is shown on Figure 3.2.

The water berthing area for the nodule transport ship, called the dock, must be deep enough to provide clearance under the ship for all loading conditions. Because large ships are considered most efficient, and the length of the navigation channels transited are relatively short, vessels may arrive at low tidal water height, 12.2 meters (40 feet) depth, and wait for higher water to transit to the berth. Water at the berth often ranges from 1 to 2 meters (3 to 6 feet) deeper than the 12.2 meter (40 foot) channel.

About six mooring dolphins, spread over a space equal to the sum of the ship length plus beam would provide adequate berthage. Near the center, a small pier with the pipeline connections would be connected by a trestle carrying a roadbed and all pipelines to shore. Swiveling pipeline equipment, that permits rapid connection and disconnection during a wide range of ship motions as the tide and ship rise and fall, would probably be installed for slurry, recycle water, and fuel.

Portable, shoreside slurry discharge units can be provided for placing in each hold at the discharge port. However, because of the relatively frequent load transfers and short voyages, equipping each vessel with slurry discharge facilities would probably be appropriate. Portable units would generally be necessary when a conventional ship is utilized for nodule slurry transport. Provision for handling ore or a slurry would almost certainly be included in any new terminal since slurry systems are of lower cost than conventional dry bulk systems.

The terminal receiving slurry pond should have capacity equivalent to at least one ship's load. Normally, capacity many times this amount would be provided for buffer stock storage. If the processing plant is nearby, the plant stockpile of from one or two month's production may be advantageously located at the terminal if space is available. This would be as much as 637,000 tonnes (700,000 tons) of material. Each ship load after dewatering would require a 3 meter (10 foot) pond which covers 0.7 hectares (1.8 acres). A water recycling tank of very large capacity is also needed. About 13,600 tonnes (15,000 tons) of seawater would provide for start up and an hour's operation.

A pumping station for onland slurry movement and a pipeline to the processing plant would take perhaps 0.4 hectares (1 acre). Utilities and parking would take the same area. As a minimum, a total of 2.4 hectares (6 acres) of land would be required for a slurry terminal. The maximum conceivable area requirement for a marine slurry terminal is about 10 hectares (25 acres).

Fuel oil storage would probably be off the terminal premises. Only a pipeline station would probably be located on the site.

Tailings volumes and weights for three-metal plants are comparable to the volume and weights of incoming nodules and might also be held at the marine terminal for shipment out for at-sea disposal if this is permitted. These tailings would be delivered in large quantities of water, (about 4 to 5 times the volume of the solid wastes). Slurry water would probably be recycled, and the amount to be stored at the terminal would depend upon the pumping rates, solids settling rates and other factors.

For tailings loading on the ship, a substantial pumping system would be installed to achieve rapid loading. Several thousand kilowatts in aggregate would be needed. This might come from diesel engines or gas turbines, or purchased electrical power. This peak power requirement

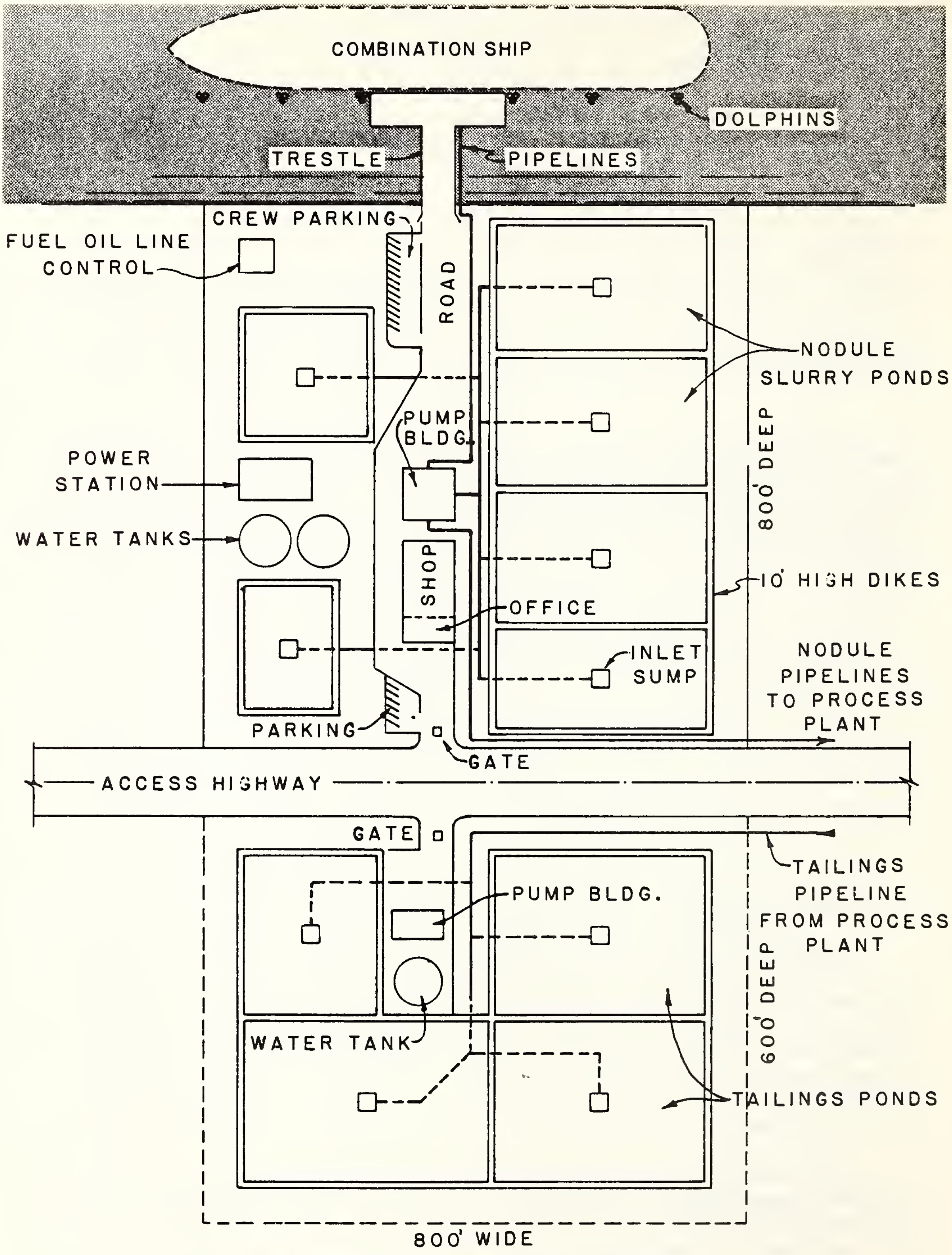

Figure 3.2 **MINIMAL SLURRY TERMINAL**

WITH ALTERNATE EXTENSION FOR TAILINGS STORAGE (HIGH THROUGHPUT)

DAMES & MOORE

would be about three times larger than the smaller slurry pumping station from the processing plant which works around the clock, rather than every few days.

Tailings waste ponds, transport water storage, and ship loading pumps could easily require at least 4 hectares (10 acres), and up to several times that for large volumes of tailings storage. In aggregate, the marine terminal for both slurry nodules and slurry wastes may occupy from 6.4 hectares (16 acres) to as much as 20 hectares (50 acres). Such a large level waterfront site would probably be difficult to find on U.S. Pacific Coast deep waterways. However, except for the mooring dolphins and pier, it would be possible to site some of the larger components several hundred meters from the waterfront.

3.3.1.2 Offshore Terminals

Moorings can be located in deep water where adequate space is available for a slurry ship to moor safely and transfer cargo. Modern mono-moorings permit the ship to swing freely about the center of the mooring area, where a surface buoy provides securing lines (or chains) to the ship. The ship is able to respond to the combination of wind, wave, and current forces to find a minimum resistance vector, and remain there with relatively little swinging motion. For a 70,000 DWT ship, an area about 610 meters (2,000 feet) in diameter is the minimum required in deep water, plus deep water fairway access channels. Water depth should exceed ship draft by the sum of at least 0.9 meters (3 feet) plus the wave height, to avoid touching the bottom. In severe weather, the slurry ship would be unable to pick up mooring lines and slurry hoses. However, if the ship is already connected, slurry pumping can continue unless the weather becomes too severe for the anchors to carry the loads safely. This system is illustrated on Figure 3.3.

Multiple mooring systems can be installed in locations with less deep water space available, as long as dominating winds, waves, or currents are moderate or are principally from one general direction. This description fits, for instance, mooring in most major rivers above tidal effects.

Offshore mono-moorings in deep water are feasible with slurry systems and larger vessels in Southern California and Texas waters. The rough ocean waters of Northern California and the Pacific Northwest probably would not be practical locations for offshore mono-mooring buoys. However, buoys and slurry pipelines could be put inside harbor entrances in deep water if space is available.

The slurry, recycle water and fuel lines, and possibly tailings waste slurry line, would all be underwater pipelines from a shore terminal to underneath the buoy, where flexible hoses rise to the buoy and float on the surface to the ship side. There the lines can be lifted aboard for connection to appropriate outlets. Mooring lines would be connected to the buoy and the ship and would be handled by a small boat upon arrival of the ship. The ship alone could drop the 30 to 45 centimeter (12 to 18 inch) hose and mooring lines quickly in an emergency. Pumping clear salt water would, within a few minutes, empty the pipe and hose of slurry down to the sea floor.

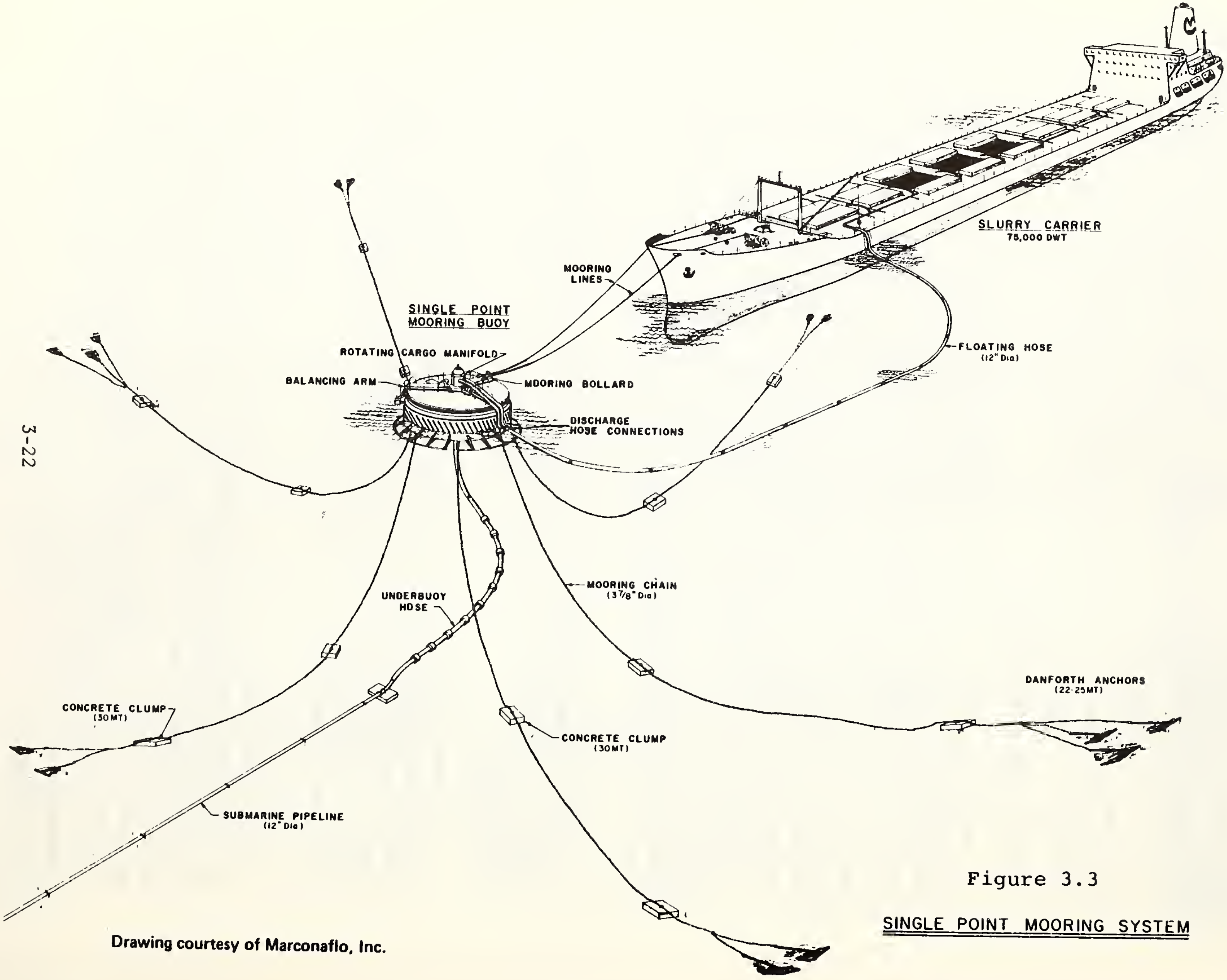

Figure 3.3

SINGLE POINT MOORING SYSTEM

Drawing courtesy of Marconaflo, Inc.

The buoy would be moored with multiple spread anchors, chains, and clump weights of adequate design for the transport vessel.

The same buoy system could be used to load waste tailing products aboard the ship for disposal at sea, with a return line of the closed loop system to recycle water for slurrying tailings. Finally, fuel oil and other bulk liquids could be handled in a separate hose and pipeline simultaneously with nodule or tailings pumping.

The water front dock, ship mooring dolphins and pipeline connections would be omitted, being replaced by the mooring. Depending upon the elevation and distance from the mooring, an auxiliary pumping station may be needed to speed off-loading of the slurry transport ship.

Support facilities are required at the waterfront for buoy mooring systems. Small craft for line handling, a work barge with derrick for anchor handling, and maintenance boats are usually specially provided for the mooring. These boats require shallow water berths and maintenance. The total installation of a mono-mooring system, including its support boats and facilities, would cost about as much as a conventional slurry berth.

Where possible, ship operators prefer to moor in a berth rather than to a buoy, even if costs are somewhat higher. Mooring in the berth facilitates ship servicing, personnel leave, and so forth.

3.3.2 Unprocessed Nodule Terminals

Terminals for receipt of unprocessed wet nodules would be conventional dry bulk facilities, such as for iron ore, bauxite, or phosphate discharge. Salt water sprays may be necessary in the ship hold, on conveyors, and on the stockpile to control dust. Essential elements of the marine terminal include the dock, mooring dolphins, a wharf or pier, unloading machinery, conveyors to the stockpile, reclaimers for loading from the stockpile to the land transportation, and a land transport equipment terminal. These are illustrated on Figure 3.4.

Discharge of the conventional ore ship could be accomplished at many existing bulk terminals in the United States. Clamshells operating through the hatch opening could each handle up to about 1800 long tons per hour, and two to four could work simultaneously for much of the time.

Quicker discharge could be provided by special shipboard self-unloading equipment, that is, conveyors in the bottom of the ship to empty each hold and a discharge conveyor mounted on a large deck boom. This equipment is not common on oceangoing vessels except in a few dedicated services, such as for coal, iron ore and bauxite transport. The equipment also must be built into a specially strengthened ore vessel. Together, this equipment and the required conveyors are very expensive. Large self-unloaders with reasonable transfer rates may have

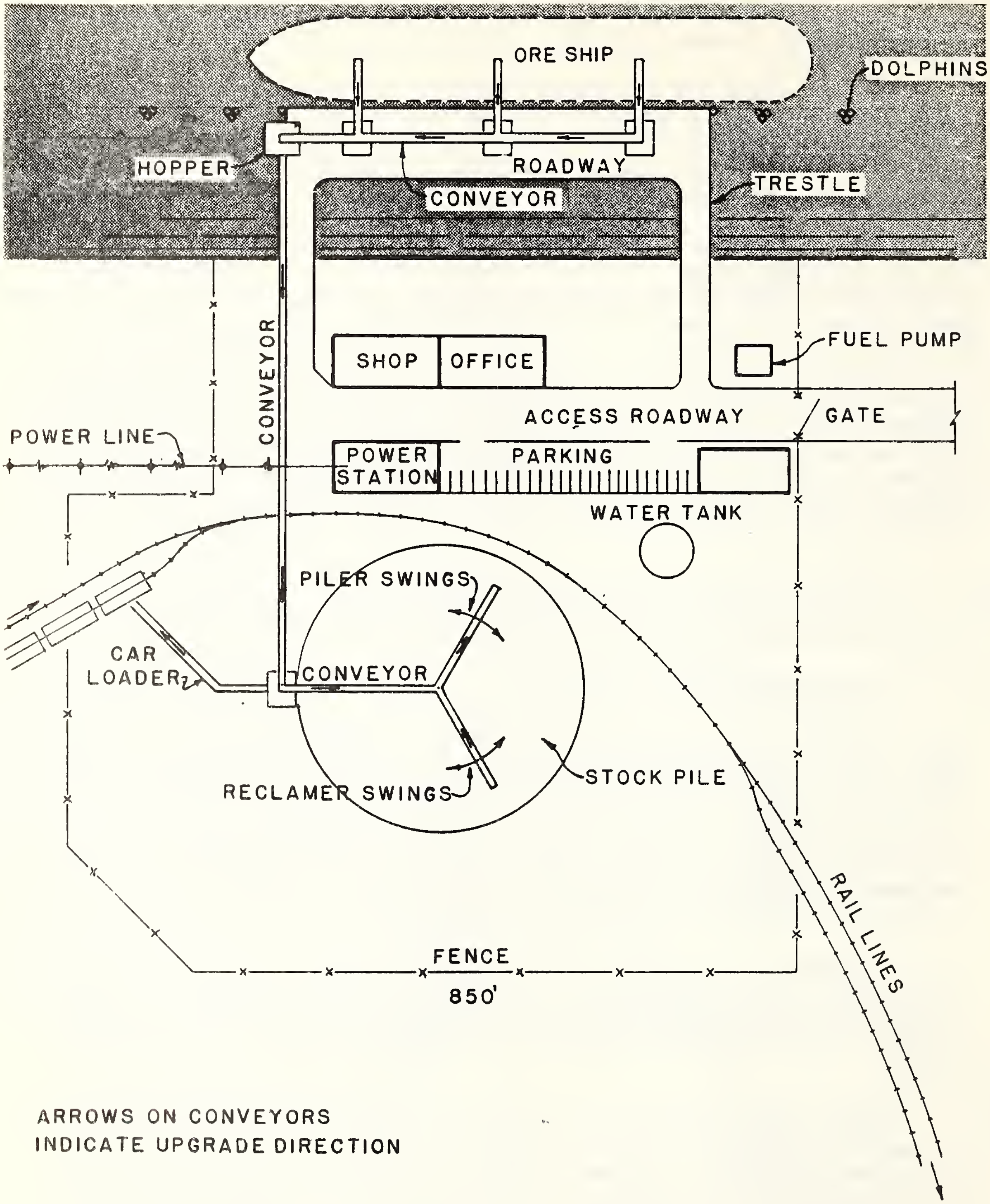

Figure 3-4. **MINIMAL WHOLE NODULE TERMINAL**

(HIGH THROUGHPUT)

extra equipment and installation costs of up to $20 million for conventional dry bulk ores, and even higher when equipped for dust control. These are reported to be much more expensive than slurry systems.

Although many of the existing conventional ore terminals could handle one to four million long tons per year of nodules, and accommodate fairly large ore ships; few are able to perform the discharge with dispatch, store adequate quantities, and connect to inland transport system. If any substantial new improvements are required to existing conventional marine terminals, the cost of the slurry system could well be lower, and be more flexible as to site location.

The ship dock would be as described for the slurry ship. The pier or wharf would be at least as long as the transport ship's cargo hold, up to approximately 198 meters (650 feet) for a 70,000 DWT ship. The unloading gear would be located on the wharf, and able to traverse the length of the ship holds. For the range of ship sizes likely, three or four bucket unloaders will be appropriate. Hulett unloaders, common on the Great Lakes for iron ore handling, would provide fast service for larger annual tonnages and for the biggest ships. Both clamshells on cranes and Hulett unloaders dump their loads into hoppers on the crane, that feed the conveyors to shore and the stockpile. An average discharge rate of 3,000 long tons per hour is assumed, which will require investment in large discharge equipment and large conveyors, probably fitted with dust control hoods, vacuum devices and water sprays.

The dry stockpile would be for tonnages comparable to that of the slurry ponds capacity, from about 91,000 to 410,000 tonnes (100,000 to 450,000 tons) of dry nodule storage. The stockpile may be covered if water spray will not adequately control the dust. One alternate may be to separate the fine material during the conveying and store it separately before onward movement.

A reclaimer at the stockpile would be needed to load nodules onto a conveyor, which would discharge either to a processing plant or into rail cars. The land transport equipment for all handling modes is described in Section 4.0.

The total land area for a three-metal plant marine terminal would begin with at least 244 meters (800 feet) on the waterfront with 12.2 meter (40 foot) depth of water at mean level low tide. The approximately 4.8 kilometers (3 miles) of railroad track and car handling equipment needed would require about 2 hectares (5 acres). Power supplies, maintenance buildings, utilities, and parking would require at least 0.8 hectares (2 acres). An adequate stockpile can probably be provided on 4 hectares (10 acres). Thus, total land required for the terminal will be about 8.1 hectares (20 acres). If only 244 meters (800 feet) wide, the terminal would extend about 335 meters (1,100 feet) deep inshore, as a minimum. If wide curves are provided for the railroad lines, much empty land would be enclosed by the tracks on the perimeter of the terminal.

An alternate ship type, the self-unloader, may be employed. The self-unloader ship carries a swiveled boom and off-loading conveyor that simply drops the bulk commodity off the end of the boom. Long booms, with controls for movement while the conveyor operates, can reach 31 meters (100 feet) ashore and erect a stockpile on a marginal wharf. Shorter booms with fixed positions are adequate to reach a hopper on a pier, where an inland conveyor would move the nodules to the stockpile, perhaps over a trestle to shore. This latter method may be desired if only two or three of the largest ships are used for nodule transport.

The efficacy of self-unloader systems for waste tailings disposal at-sea is questionable. Conventional combination or ore ships would be unable to dispose of waste tailings at sea, because both ship types would not have the required material handling capabilities. Therefore this unprocessed nodule marine terminal does not provide for return to sea of waste tailings.

3.3.3 Dried and Ground Nodule Terminals

The marine terminal for dried nodule material may resemble a dry bulk chemical, fertilizer, or cement terminal. Enclosed handling and storage equipment would almost certainly be required for dust control and to reduce loss of material. Because of the 30 percent loss of weight, lower cargo tonnages are handled, but at a slower rate and at greater unit expense. At the same mining rate, 11,200 long tons per day, a lower weight of dried material would be stored aboard the mining ship, and a minimal number of transport ships is required. Therefore the interval between transport ship arrivals would be longer and the number of ship voyages would be less. All these elements combined dictate that a relatively low throughput terminal would be needed, with a slower handling and smaller storage. This type of terminal is illustrated on Figure 3.5.

The essential elements of a dried nodule terminal are the ship dock, the pier or wharf, shoreside or shipboard pneumatic suction cargo unloaders, and an enclosed conveying system over a trestle to shore and to the stockpile building. From the storage, another enclosed conveyor would lead directly to the processing plant or to closed hopper car loading equipment.

A self-unloading, dry ore ship could be constructed with onboard pneumatic discharge equipment. The ship berth would be similar to a tanker or slurry terminal for a self-unloading ship. The dry nodule ship would be similar to existing, but much smaller, cement carriers. Development of special ships of this type would be very expensive.

For conventional ore or combination ships without cargo handling gear, pier-mounted equipment would be required. A platform the length of the ship cargo holds, plus mooring dolphins at each end, would be the minimum requirement. Pneumatic ship unloaders would be needed at each

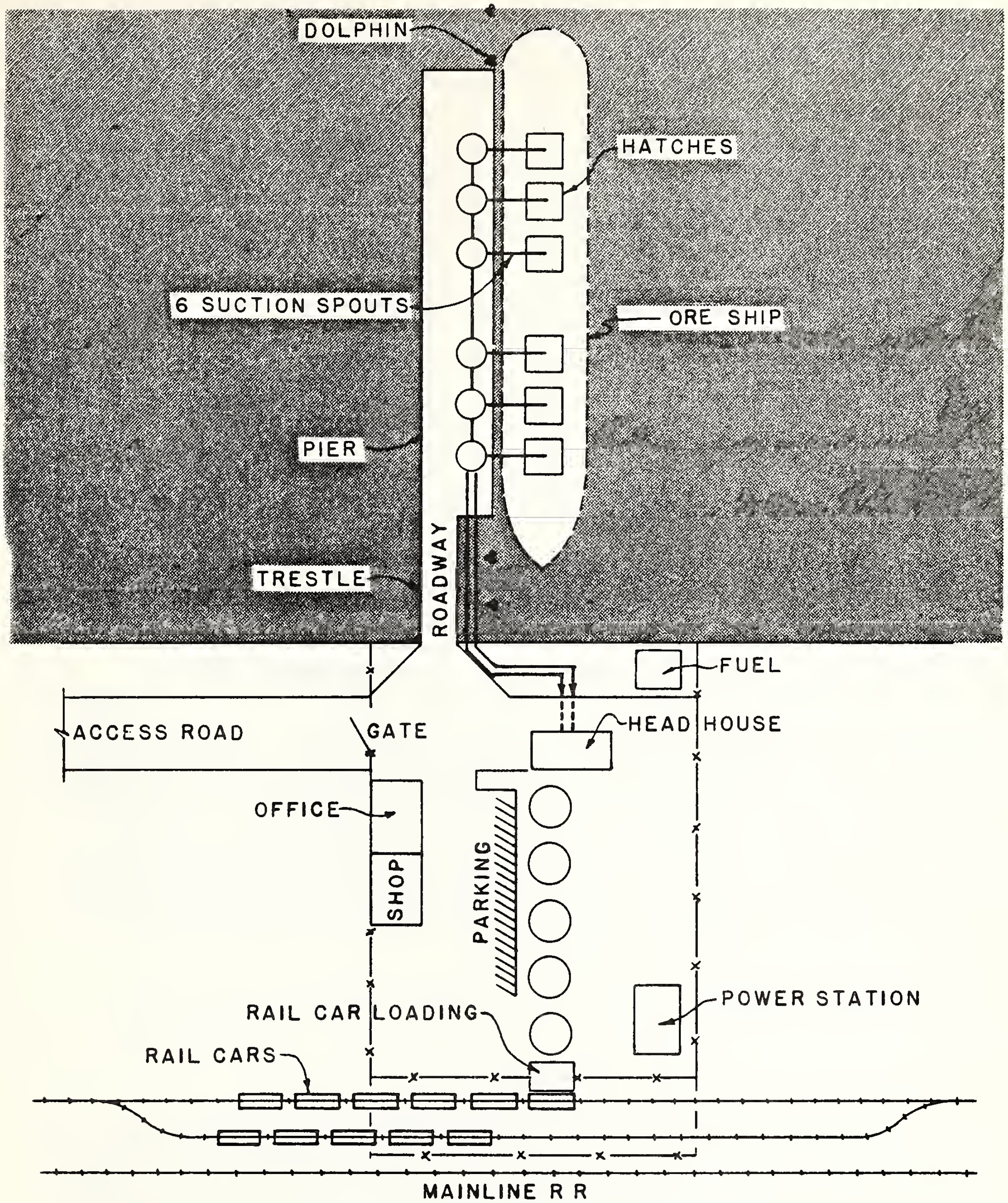

Figure 3.5 **MINIMAL DRIED NODULE TERMINAL**

(LOW THROUGHPUT)

cargo hold to achieve desired discharge rates of 1500 long tons per hour. This results in a two day unloading period if working continuously as assumed, and three days, working 2 shifts per day for the maximum size ship.

With either ship or shore discharging gear, the pneumatic pipelines to shore would lead directly to storage buildings or silos. A maximum shipload of about 66,000 long tons of dry material, at a density of 0.28 cubic meters per tonnes (10 cubic feet per long ton), would require a silo 14 meters (46 feet) in diameter and 31 meters (100 feet) high, plus space for handling. A row of three to seven silos would provide adequate buffer storage for the larger nodule mining system.

The silos could continuously feed a pneumatic pipeline to the processing plant at the rate of only 330 long tons per hour. A distance of several kilometers is feasible for pneumatic conveyors, but pumping stations would be required along the line. The silos could also dump directly into enclosed or covered hopper cars at about 20 to 50 long tons per minute. A daily unit train would be loaded in about an eight hour day to deliver the dried nodule material to a distant processing site.

The silos would require about 0.4 hectare (1 acre); the railcar area about 2.0 hectares (5 acres), as described before; and the pneumatic vacuum system, power supplies, maintenance, and parking another 1.6 hectares (4 acres). Under the most compact arrangement, at least 4 hectares (10 acres) of land plus waterfront, would be needed.

The dried material handling can be accomplished in conventional ore ships or in combination ships. As discussed in the raw nodule terminal section, disposal of waste tailings at sea could not be accomplished by these ships without additional equipment being installed, or without considerable added energy consumption for drying tailings onshore. Therefore, a combination of dried and ground nodule transport with at-sea tailings disposal using the transport vessel is very unlikely. Thus, a terminal for dried and ground nodules would probably not be sized for tailings storage and handling.

3.4 SUMMARY OF TRANSPORT FLEET REQUIREMENTS AND PORT REQUIREMENTS

3.4.1 Summary of Nodule Transport Form

Nodules are likely to be transported to port in one of the following forms; slurry, raw (as raised) or dried and ground. Of these three forms slurry is the simplest to handle and probably least costly. The dried and ground form, which reduces the weight by 30 percent inbound, presents potential materials handling problems and would also probably have the slowest transfer rate for unloading. In general, at sea drying of the ore appears to be pratical only if the ore must be transported long distances such as to a Gulf Coast port. Conventional bulk handling may be feasible, but has problems related to dust control and the handling of nodules at sufficiently high transfer rates.

If the transport vessels are also to be used for at-sea tailings disposal, assuming such disposal is permitted, then the transports would likely be designed for inbound nodules to be in slurry form. Since for three-metal plants the volume of tailings would slightly exceed the volume of inbound slurry, the ship sizing and equipment requirements would be controlled by the tailings disposal requirements.

3.4.2 Transport Fleet Description

3.4.2.1 Three-Metal Plants

For the three-metal plants on the Pacific Coast of the U.S., the vessels listed in Table 3.13 have been estimated as appropriate.

TABLE 3.13

SUMMARY OF TRANSPORT SHIP REQUIREMENTS -
MINING SITE B - 3-METAL PLANT

Site B to:	Southern California		Pacific Northwest		Central Texas
Number ships	2	or 3	2	or 3	See Below
DWT for:					
Slurry only	63,000	44,000	87,000X	58,500	55,000* -7
Slurry & Waste	74,000M	49,500	104,500X	62,300	55,000* -8
Whole Nodules	73,000M	47,000	92,400X	61,600	55,000* -8
Dried MaterialΔ	56,000*	32,500	71,500M	44,000	55,000* -6

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*Panamax ships
X Not reasonably acceptable in navigation channels
M Marginally acceptable in navigation channels
Δ Dried nodule weight is 70% of wet weight

For a Texas based plant, the most likely ships would be the Panamax size. All of the other ship sizes, given the choices reasonably available, range from 44,000 DWT to 74,000 DWT.

If the prospective mining site is at the Western boundary of the area of interest, (the International Date Line), the distance of either Southern California or the Columbia River is about 7,040 kilometers (3,800 nautical miles). Table 3.14 indicates the combinations of approximate vessel sizes and numbers possible for transport of nodules from this area, summarized in the same format as above.

TABLE 3.14

SUMMARY OF TRANSPORT SHIP REQUIREMENTS - WESTERN BOUNDARY - 3-METAL PLANT

Western Boundary to:	Pacific Northwest or Southern California			Central Texas
Number Ships	3	4	5	See Below
DWT for:				
Slurry Only	91,500X	70,000	55,000	55,000* -11
Slurry & Waste tailings	108,000X	80,000X	63,000	55,000* -12
Whole Nodules	111,000X	81,500X	56,500	55,000* -12
Dried MaterialΔ	83,000X	60,000	46,500	55,000* -8

See Footnotes to Table 3.13.

Clearly the additional sailing distance to a deep ocean mine site further away will require more vessels, or larger size, or a combination of both. However the Central Texas processing plant can still be served only by Panamax size ships, but in larger numbers to handle the volume of nodules. For the longer distances, drying the nodule material to remove the water and reduce the weight transported would be much more beneficial, and fuel would probably be brought in from Indonesia rather than from the United States.

3.4.2.2 Four-Metal Plants

In the Gulf Coast four-metal combination, two Panamax ships of about 55,000 DWT represent a likely choice of the operating consortia; although slightly smaller ships would be adequate under the conditions assumed.

TABLE 3.15

SUMMARY OF TRANSPORT SHIP REQUIREMENTS MINING SITE B - 4-METAL PLANT

Site B to:	Southern California		Pacific Northwest		Central Texas
Number Ships	1	2	1	2	See Below
DWT for:					
Slurry Only	43,000	22,000	56,000	30,000	55,000* -2
Slurry & Waste	51,000	24,000	63,000	31,000	45,000 -3
Whole Nodules	48,500	23,000	56,500	30,000	49,000 -3
Dried MaterialΔ	36,500	---	46,500	---	48,500* -2

See Footnotes to Table 3.13.

TABLE 3.16

SUMMARY OF TRANSPORT SHIP REQUIREMENTS - WESTERN BOUNDARY - 4-METAL PLANT

Western Boundary To:	Either Southern California or Pacific Northwest		Central Texas
Number Ships	1	2	See Below
DWT for:			
Slurry Only	84,500X	41,700	47,000 - 4
Slurry and Waste	89,200X	44,000	49,000 - 4
Whole Nodules	99,500X	48,000	48,000 - 4
Dried MaterialΔ	73,500M	37,000	44,000 - 3

See Footnotes to Table 3.13.

In practice all the vessels for 3-metal or 4-metal operations have about the same operating characteristics except for their size and draft, which require different channel depths and may require dredging for moorings at some locations. Therefore the remainder of this study will discuss combination carriers ranging in size from 44,000 DWT to 70,000 DWT. These ships would probably be about as large in capacity as the navigation channel depths to the marine terminals would allow.

3.5 DETAILED DESCRIPTION OF MOST LIKELY SEA TRANSPORTATION AND PORT REQUIREMENTS

3.5.1 Most Probable Transport Vessels

Table 3.17 lists possible process plant locations, and transport vessels judged as most likely to be selected from the information now available. External factors played a major role in this judgment, and economic factors not adequately quantifiable at present were also entered into this identification. The actual systems which the industry would plan to use would be dependent on total system (from mining through waste disposal) economies.

TABLE 3.17

LIKELY TRANSPORT VESSELS

Location	Process	Rate	Number Ships	Minimum DWT	Ore Type
Central Texas	All	3-Metal	6	55,000*	Dried
Central Texas	All + Dumping	3-Metal	8	55,000*	Slurry
Central Texas	All	4-Metal	2	55,000*	Dried
Central Texas	All	4-Metal	2	55,000*	Slurry
Pacific Northwest	All	3-Metal	3	58,500	Slurry
Pacific Northwest	All + Dumping	3-Metal	3	62,300	Slurry
Pacific Northwest	All	4-Metal	1	56,000	Slurry
Pacific Northwest	All + Dumping	3-Metal	1	63,000	Slurry
Southern California	All	3-Metal	2	63,000	Slurry
Southern California	All + Dumping	3-Metal	2	74,000	Slurry
Southern California	All	4-Metal	1	43,000	Slurry
Southern California	All + Dumping	4-Metal	1	51,000	Slurry

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*Panamax Size

3.5.2 Fleet Resource Requirements

The ships for slurry, raw, or dried nodules are estimated to range in size between about 55,000 DWT-Panamax size and 70,000 DWT, the approximate size of the largest ships able to transit most navigation channels.

These vessels may be either of United States or foreign registry, as current law restricts only the domestic trade (defined as movements between American ports) as being reserved for U.S. built, owned, and manned vessels. The ships could also be built abroad and operated under U.S. registration in this foreign trade. There is currently legislation pending before the Congress which would establish a domestic legal regime for authorizing deep seabed mining during the period before agreement to a Law of the Sea Treaty encompassing deep seabed mining is reached. Such legislation could require U.S. construction and registry or permit the alternatives of foreign construction-U.S. registry or both foreign construction and foreign registry. Foreign vessel construction and operating costs could be on the order of one-half of U.S. ship costs.

The design of the foreign vessels probably meet only the international standards for construction, and not higher U.S. standards, unless built foreign and registered in the United States. The principal concerns of international vessel standards are safety of life at sea; vessel structural and mechanical integrity; pollution control of petroleum, sewage, dangerous chemicals, and wastes; and skills of the vessel's officers and crew. United States laws are more restrictive in most of these areas.

3.5.2.1 Fuel

The pollution of the seas by petroleum and its products is of major concern, and applies to the nodule mining and transportation ships because these ships both carry and burn fuel oil, and receive fuel aboard in a bunkering operation. The foreign ship for this service will probably be diesel powered for maximum fuel economy and construction cost savings. American ships have almost all been steam boiler and turbine powered, and burn heavy Bunker C or residual fuel oil, slightly cheaper than diesel fuel but consumed at a greater rate.

Table 3.18 summarizes "typical" nodule transport ship sizes and fuel consumption rates. For 11 to 32 days for round voyages, the range of time in this study, total transport ship fuel consumed ranges from only 650 long tons per voyage to 2,200 long tons per voyage.

TABLE 3.18

BULK SHIP FUEL CONSUMPTION

	Power		Fuel Consumption (Long Tons per day)	
DWT	Horsepower	Kilowatts	Diesel	Residual Fuel Oil
40,000	15,000	11,200	48	64
50,000	16,000	11,900	60	66
60,000	17,000	12,700	62	69
70,000	18,000	13,400	64	70
80,000	19,000	14,200	66	73

Fuel consumption by the mining ship is not known. However, consumption of less than 200 long tons per day is expected. Power on the mining ship would be needed principally for propulsion, for mining equipment, pumps and ore preparation and loading. For drying of nodules, a substantial volume of combustion gases would be needed at about 175°C (347°F). This could be exhaust gas from the boiler reheated by turbine exhaust steam, or could be from producing additional combustion gas for the purpose of drying. Thus, fuel oil transported to the mining ship could range from less than 200 to as much as 1,000 long tons per voyage of each transport ship. These are relatively small volumes of petroleum and can be easily handled by standard ship fuel oil transfer pumps and equipment.

3.5.2.2 Supplies

Other machinery-related supplies would be shipped to the mining ship onboard nodule transport ships and would be delivered to the mining vessel by a small boat. These supplies include lube oil, boiler and distiller feed water treatment chemicals, repair parts, food, paint and other small items.

Fresh water for boiler water makeup and human consumption would probably be distilled in sea water evaporators aboard the mining ship, rather than carried out from shore. However, water transport is possible in large volume on all ship types, and would be readily pumpable to the mining ship.

Sea water would probably be used mostly for cleaning of the ship's holds, followed by a fresh water rise. Ballast tanks would probably remain clean for all vessels, because the high density of the nodules permits generous volume of tanks for segregated fuel, ballast, fresh water, and cargoes.

Sewage treatment and holding devices are common on all new ships, and would be expected on the transport ships. Garbage and trash incinerators are also common.

3.5.2.3 Shipyards

The construction of two to eight new mining and transport ships between 1979 and 1982 is within the existing capabilities of many American shipbuilding yards. Few if any additional resources would be required at the construction yards; however, several thousand man-years of labor would be expended to manufacture the ship and its components. Steel, the largest item required for each ship, is an insignificant portion of existing U.S. steel plant capacity, which is not now being fully utilized.

The principal requirements for vessel maintenance are the same as for existing tankers and bulk ships of similar size and power. Hull preservation would be a continuous operation for spot surface repairs in the American port. Engine room repairs and maintenance would also be undertaken at the marine terminal. The major demand would be for drydocking, and several Pacific and Gulf of Mexico coastal shipyards have adequate facilities that are at present under-utilized. Each year during the short down period of the mining ship, the transport vessels would normally spend a few days at a drydock.

The mono-mooring buoy, if used, probably would be drydocked every several years. The small craft fleet associated with the mono-buoy operations would probably be maintained in existing near-by boat yards. The incremental docking traffic from any one mining program would be an almost imperceptible increase in business, and not generate any need for new repair or docking facilities. Existing facilities are also available and adequate for equipment manufacture and testing of new equipment and procedures related to shipping.

3.5.2.4 Labor

The shipboard crew would range between 26 and about 40 for each vessel, depending upon the propulsion plant and type of cargo handling on board, if any. Ship size would have little effect on crew size.

Because of the short voyage and frequent calls in the U.S., at least 1-1/2 men would be employed for each berth. For a three ship fleet of large slurry vessels, a crew pool of 160 men would be needed, plus about 30 engineers, maintenance and management staff ashore.

3.5.3 Port Requirements

3.5.3.1 Summary of Marine Terminal Requirements

Tables 3.19 and 3.20 list the minimum total land area required for the three three basic nodule transport handling methods, and for the slurry system handling waste tailings for disposal at [illegible] should this practice be implemented. The terminals requiring railcar yards may be more efficient if much larger areas are provided. The most important space requirement in a marine terminal would be for nodule storage either in slurry or whole form; the dried nodule storage in buildings takes the least space but would be the most expensive means of storage.

Fuel for all ships, and for delivery to the mining ship, may be piped directly to ship side for bunkering while cargo is being discharged. An alternate would be delivery by barge to the offshore side of the ship. This bunkering is common, and adequate bunkering barges are available to provide this service.

TABLE 3.19

MINIMUM MARINE TERMINAL AREA
3-METAL PLANT

Nodules Handled	Slurry	Slurry Plus Waste	Whole	Dried
Pier Type	Dolphins	Dolphins	Wharf	Pier
Discharging type	Ship pump	Shore pump	Bucket Unloaders	Pneumatic
Discharging rate (L.T./hour)	4,000	4,500	3,000	1,500
Land Area-Hectares (Acres)				
Equipment	0.4 (1)	0.8 (2)	1.2 (3)	1.2 (3)
Storage	4.4 (11)	8.4 (21)	4 est (10 est)	0.4 (1)
Railroad	0 (0)	0 (0)	2 (5)	2.0 (5)
Utilities, Parking, etc.	0.4 (1)	0.8 (2)	0.8 (2)	0.8 (2)
Total	5.2 (13)	10 (25)	8 (20)	4.4 (11)
Employment	33	48	58	47

Notes: Neither waterfront pier area nor nodule processing space is included.

TABLE 3.20

MINIMUM MARINE TERMINAL AREA
4-METAL PLANT

Nodules Handled	Slurry		Slurry Plus Waste		Whole		Dried	
Pier Type	Dolphins		Dolphins		Wharf		Pier	
Discharging type	Ship pump		Shore pump		Bucket Unloaders		Pneumatic	
Discharging rate (L.T./hour)	3,600		4,050		2,700		1,350	
Land Area-Hectares (Acres)								
Equipment	0.4	(1)	0.8	(2)	1.2	(3)	1.2	(3)
Storage	1.6	(4)	3.2	(8)	1.6	(4)	0.4	(1)
Railroad	0	(0)	0	(0)	1.2	(3)	0.8	(2)
Utilities, Parking, etc.	0.4	(1)	0.8	(2)	0.8	(2)	0.8	(2)
Total	2.4	(6)	4.8	(12)	4.8	(12)	3.2	(8)
Employment	28		40		49		39	

Since no port call is made at the mining site, a shoreside berth is most desirable in the United States. However, the slurry systems permit use of offshore moorings and pumping ground nodules ashore, and fuel and waste tailing loading if desired. The principal advantages of offshore mooring buoy transfer terminals are the deeper water available and reduction of waterfront construction. Among the disadvantages are higher operating costs, delays in moorings and cargo handling, and some inconvenience in fueling, maintenance, berthing, and personnel leave.

The minimum 6 hectare (15 acre) area required for a marine terminal for the higher production rate requires a site of about 244 meters (800 feet) along shore by 253 meters (830 feet) inland which should be available in many areas. The larger areas for waterfront processing, up to 80 hectares (200 acres) with rail lines, are not readily available anywhere at ports on the Pacific Coast. The approximate channel depth of 12.2 meters (40 feet) at low tide in salt water should be available at several locations, but greater depths are generally not available. The smaller throughput typical of a four-metal plant would still require about 244 meters (800 feet) of waterfront for the docking area. For inland movement by rail where slurry pumping is not performed, the track space required at reasonable curvatures for efficient operation may increase the total site dimensions, although much of the space within the tracks may be unused.

Employment figures are the number of equivalent full time jobs at the terminal. Permanent positions include watchmen, slurry system operators, maintenance and repair craftsmen, and storage system operators. Skills required at irregular schedules include tankermen, stevedores, equipment operators, and railroad men. The ship crews are not included in the employment at marine terminals.

A small unit train of only 50 cars of 91 tonnes (100 ton) capacity requires 915 meters (3,000 feet) of track minimum. This would be difficult to install in a space as small as 244 meters (800 feet) wide by 135 meters (443 feet) deep, which is about 3.2 hectares (8 acres). Adjacent land strips for the approach and departure rail tracks would be needed.

Construction of the waterfront pier or wharf of the marine terminal would probably require some dredging and disposal of material. This subject will be discussed under the navigation section.

Building of dolphins, piers, wharves, and trestles to standard civil engineering codes would take months. Pile drivers, barge cranes, and parts manufactured on shore at existing factories would be utilized. Depending upon the location and costs, reinforced concrete or structural steel construction materials may be used for pilings and deck. If local storage or fabrication is required, the site of the completed marine terminal would be used. Components of slurry pipelines and pumping stations, or conveyors and unloading machines, and utilities equipment would all be assembled on the marine terminal site. Some large units may be moved in by barge, but most would arrive by rail or truck from the supplier.

Site preparation probably would include filling and leveling, installation of fencing and utilities underground, paving of roads and railroad track laying. Relatively few small buildings would be constructed, probably of prefabricated metal type. However the silos for dried nodule material would represent a major concrete construction project on the terminal site, requiring a temporary sand and gravel plant. Almost all the equipment for the terminals would be manufactured and assembled at existing factories and then installed and tested at the site. A total construction time of one to two years would be needed after receipt of all necessary permits.

Fresh water would be needed both during the marine terminal construction period and the terminal operation. Because of the use of salt water on the nodules, a cleansing spray of fresh water over buildings and machinery would be most helpful in reducing metal corrosion at the terminal. Fresh water use by the terminal crew would be small, as perhaps only 15 to 30 persons would be working there during ship cargo handling, and even fewer most of the time. As a result, little sewage, garbage, trash, or auto pollution may be generated. A two lane access road to public highways, and to the waterfront terminal would be necessary. Either a pipeline or railroad right of way would be needed to transport nodules to the processing site.

The operation of the pumps, conveyors, ship unloading machinery, stackers, dust control fans, reclaimers, and slurry and spray jets would produce some noise, especially when ship cargo handling is underway, and when power is generated on the terminal site. Use of purchased electrical power would require high voltage transmission lines. A fuel pipeline may be installed, for either ship bunkering, or to generate power, or both. The fuel consumption rate at the terminal would be small.

Substantial labor effort and equipment installation would be devoted to avoiding loss of nodule material. Reclaiming of spillage from conveyors, spills from slurry pipes (or from waste tailings) and ship and pier cleanings would probably be largely mechanized, using appropriate devices. Traps and enclosures should be quite effective, and delays in nodule recovery would not cause contamination (Harker, 1974).

3.5.3.2 Navigation Resource Requirements

Navigation resources include channels, aids, and controls. The navigation channels into selected U.S. ports on the Pacific and Gulf of Mexico were described earlier (see Table 3.3). Each port has a unique set of physical characteristic which assist or limit ship transportation in the channels. These include other vessel traffic; river flow and tidal rise and fall and their currents; fog, rain, snow, and river curvature affecting visibility; aids to navigation and radar-assisted shore traffic direction; tug assistance and similar activities. The depth and width of navigation channels set upper limits on the draft of transiting vessels, and thus directly limit the size, capacity, and efficiency of the ships (Kray, 1973).

Increasingly, large size ships are directly and adversely affected by all of these factors. Larger ships are less maneuverable, slower in stopping, and occupy more of a restricted channel than smaller vessels. Large ships in tidal or flowing currents are strongly pushed and not well able to control their heading or position in confined quarters. Reduced visibility hinders navigators in meeting obligations to keep clear, and prompt action is essential to avoid collisions or groundings. Channel markers are not always on station, and rapid shoaling near channel limits cannot be detected early enough on most ship depth sounders. Radar-assistance to navigators from Coast Guard shore stations is advisory and only available to large ships and not the small boat traffic. Tugs are sometimes inadequate for the tasks of keeping large ships in position and channel, or from bumping into bridges, docks, shoals, and other vessels.

Although each of these resources can be identified for a particular area, to quantify the benefit from their presence in any particular degree is most difficult. Adequate data is probably not available to estimate the likelihood of grounding with or without tugboats in any specific channel, for example. If data were available, analysis would probably conclude that operating managements have, through experience, learned to make judgments that are close to optimum. These include when to use tugs, when to enter a channel, where and how to berth, when to back down and change rudder position, and like decisions.

All of the navigation channels considered here have been used many times by very large ships, over 100,000 DWT, on suitable occasions. Even 70,000 DWT ships, with about 55,000 long tons of cargo, have transited the Panama Canal regularly. These ships have not had the advantage of regular calling and special port facilities, and yet accidents rarely happen. Given the infrequency of channel use by these large ore carriers, little traffic increase can be measured which would raise the exposure and probability of collision. From past experience, the expected incidence of accidents would probably be longer than the project life.

4.0 ON-SHORE NODULE HANDLING AND TRANSPORTATION SYSTEMS

4.1 BACKGROUND ON PORT-TO-PLANT TRANSPORTATION

Many commodity movements in large volumes are now taking place to and from seaports in the United States, and the entire world. Within the United States, iron ore is moved in enormous volumes by rail cars in Minnesota to Great Lake ports. Bauxite is imported from Jamaica and South America to the Pacific Northwest and the Gulf Coast. Several million tons per year of phosphate rock are exported from Tampa Bay after rail transport from the Florida mines. About twenty million tons per year of coal are moved by railroad to Hampton Roads and to Los Angeles for shipment. Coal is also shipped from Toledo for Great Lakes distribution.

The technology and equipment for handling large volumes of materials, as would be required in manganese nodule mining, from a port to a process plant site is available in the United States.

4.2 SCOPE AND METHODOLOGY

This section deals with the on-shore handling and transportation of the manganese nodules. The handling and storage procedures and facilities required at the port were discussed previously in Section 3.0. The remainder of this section is devoted to the transportation of the manganese nodules, in a variety of forms, from the port to the processing plant site.

The purpose of this portion of the study is to identify and evaluate the various possible methods of on-shore transportation in order to identify the systems most likely to be used by industry.

Three port areas, as discussed in the preceeding section, were considered. Assuming that waste disposal does not dictate otherwise, the plant site would be located as close to the port as is economically and practically possible. For the purposes of the on-shore transportation study, it was assumed that the plant would be within 100 miles of the port.

The various possible methods of on-shore transportation were evaluated on the basis of technical feasibility, economic feasibility, environmental constraints and legal constraints.

4.3 MATERIAL TO BE HANDLED

The on-shore transportation analysis considers nodules in raw, slurry, and dry ground forms. While it was concluded that it is most likely that nodules will be received at ports in slurry form where mine site to port distances are not excessive and in dry ground form when distances are large, the other forms were not excluded because in practice the form will be determined upon total system economies.

4.4 TRANSPORT OF RAW NODULES

If the manganese nodules are delivered to the port in the form of raw nodules, the following modes of on-shore transportation are considered possible: rail system, truck haulage, conveyor system and slurry pipeline. The slurry pipeline scheme would require that a grinding mill be constructed at the port to grind the raw nodules to a gradation suitable for hydraulic transport. Such grinding is ultimately necessary for processing the nodules, therefore, grinding at the port merely requires shifting the facility from the plant to the port and is not an additional step in the process. Grinding at the port was not considered a part of the transportation costs. The transport systems considered are described in succeeding sections.

4.4.1 Rail System

Railroad haulage was considered for the raw nodule form. It was assumed that the plant would be located such that existing rail lines could be used with no new track construction. It was further assumed that unit trains dedicated to manganese nodules haulage would be used. The characteristics of the assumed rail haulage system are as follows:

Freight Cars. Gondola cars of 91 tonnes (100 tons) capacity were assumed. These cars would be fitted with removable covers to eliminate the possibility of wind loss of nodule dust during transit.

Locomotives. Locomotives were assumed to be diesel-electric. Electric locomotives require less maintenance than diesel-electric types; however, the electrical power cable system required represents a cosiderable investment and maintenance expense. Electric locomotives are generally used only for short lines or high capacity lines and are considered impractical for the type of service considered here.

It was assumed that the trains would travel at an average speed of 24 km/hr (15 mph) for short hauls where a significant length of the haul may be through urban areas surrounding the port. For longer haul distances, an average speed of 40 km/hr (25 mph) was used.

Route. It was assumed that if rail transport is used, the plant will be located to maximize use of existing track systems. For the purpose of estimating costs it was assumed that no new track construction would be required except for sidings and new spur lines at the port and plant.

Loading and Unloading Facilities. The loading facility required at the port was discussed previously in Section 3.0.

Unloading of raw nodules would probably be by bottom dumping with stockpiling in storage areas. Transfer conveyors would be needed to transfer the raw nodules from the dumping area to the storage areas. Dust control in the form of spraying or covering would be required.

The rail system equipment required to transport raw nodules for the two production rates is given in Tables 4.1 and 4.2.

TABLE 4.1

RAIL EQUIPMENT REQUIRED FOR TRANSPORT OF RAW NODULES

3-METAL PLANT

Distance Plant-to-Port in Kilometers	(Miles)	Locomotives Per Unit Train	Rail Cars Per Unit Trains	Number of Trains Required
8	(5)	2	18	1
80	(50)	3	60	2
161	(100)	3	60	2

TABLE 4.2

RAIL EQUIPMENT REQUIRED FOR TRANSPORT OF RAW NODULES

4-METAL PLANT

Distance Plant-to-Port in Kilometers	(Miles)	Locomotives Per Unit Train	Rail Cars Per Unit Trains	Number of Trains Required
8	(5)	1	6	1
80	(50)	2	36	1
161	(100)	2	36	1

4.4.2 Truck System

Truck haulage from port-to-plant was also considered for transporting the raw nodules. The following equipment was assumed for this system:

Trucks. Truck size will be limited by highway load limit regulations. It was assumed that units with an 18 tonnes (20 tons) capacity would be used. These units would be covered to prevent loss of fine material through wind erosion. An average travel speed of 32 km/hr (20 mph) was assumed for short hauls where a significant length of the haul may be through urban areas surrounding the port. For longer haul distances, an average speed of 80 km/hr (50 mph) was assumed.

Unloading Facilities. The unloading and storage facilities at the plant will be similar to those discussed above for the rail system.

The assumed number of shifts of operation and the number of trucks required to transport the raw nodules are presented below in Tables 4.3 and 4.4.

TABLE 4.3

TRUCK OPERATION AND EQUIPMENT REQUIREMENTS FOR TRANSPORT OF RAW NODULES

3-METAL PLANT

Distance Plant-to-Port In Kilometers (Miles)		Number of Shifts Assumed	Number of Trucks Required
1	(0.66)	1	22
8	(5)	2	20
80	(50)	3	66
161	(100)	3	119

TABLE 4.4

TRUCK OPERATION AND EQUIPMENT REQUIREMENTS FOR TRANSPORT OF RAW NODULES

4-METAL PLANT

Distance Plant-to-Port In Kilometers (Miles)		Number of Shifts Assumed	Number of Trucks Required
1	(0.66)	1	7
8	(5)	1	12
80	(50)	2	30
161	(100)	2	60

4.4.3 Conveyor System

Conveyor systems were considered for transporting raw nodules to plant sites adjacent to and up to about 32 km (20 miles) from the port. Long distance, high capacity conveyor systems have been in use in the mining, construction and bulk handling industries for many years (Malone, 1964; Douglas). Existing equipment and technology are suitable for transporting manganese nodules. The systems were assumed to operate 24 hours per day, seven days per week, for 330 days per year. Conceptual designs of conveyor systems for the various production rates were prepared using published data and procedures (Pfeilder et al., 1968). The resulting system characteristics can be summarized in Table 4.5.

TABLE 4.5

CHARACTERISTICS OF CONVEYOR SYSTEM

	3-Metal Plant	4-Metal Plant
Throughput	450 mtph (495 tph)	136 mtph (150 tph)
Belt Width	76 cm (30 in.)	61 cm (24 in.)[1]
Belt Speed	76 m/min (250 fpm)[2]	same
Configuration	Enclosed for Dust Control	same
Loading	Horizontal Vibrating Feeder	same

Notes: 1) 61 cm is considered minimum belt width for overland conveyor systems
2) maximum recommended speed to reduce dust potential

4.4.4 Slurry Pipeline System

If the ore is delivered to the port in raw nodule form, it would still be possible to transport it to the plant by means of a slurry pipeline. This scheme would entail shifting the location of the grinding mill from the plant location to the port. A slurry pipeline system would consist of the following components:

1. Raw Nodule Storage at the Port. The raw nodules will be unloaded from the bulk carrier ships and stockpiled at the port as previously described in Section 3.3.2 and as shown on Figure 3.4.

2. Grinding and Slurrying Facility at Port. The raw nodules will be reclaimed from the stockpiles and fed to a grinding facility. The ground ore will then be fed to the slurry pump station sump, mixed with water and agitated for hydraulic transport.

3. Pumping Station. A slurry pumping station would be required at the port. Its location would be adjacent to the storage pond. Preliminary computations indicate that for a plant site 13 kilometers (8 miles) or less from the port, a bank of centrifugal pumps in series could be used. For distances longer than 13 kilometers (8 miles) booster pump stations would be required. Positive displacement pumps could transport the slurry about 56 to 64 kilometers (35 to 40 miles) without the need for intermediate booster stations; however, line pressure would be much higher.

4. Pipeline. A buried, welded steel pipeline would be used to transport the slurry. A second line could be installed to return plant waste and/or decant water to the port for disposal at sea.

5. Storage Pond at the Plant. A pond would be required at the plant site to provide ore storage. This pond would provide for storage in case of a plant shut-down and would also provide a surge pile of ore in case of a pipeline shut-down.

4.5 COMPARISON OF RAW NODULES TRANSPORT SYSTEMS

Port location and the haul distance from port to the plant are both unknown at this time. Thus, identification of the most likely mode of land transportation cannot be based on site specific criteria. For the purpose of this study, the various possible transportation systems were compared in a generalized manner by considering the following parameters:

Economic Considerations
Environmental Impacts and/or Legal Implications
Safety Considerations

4.5.1 Economic Considerations

Capital costs and operating costs were developed for each of the transport systems described above. Capital costs were derived using data obtained from manufacturers. Operating costs were estimated according to procedures set forth by Pfleider (1968) using present-day average labor and fuel prices while electrical energy costs were computed using present-day rate schedules provided by utility companies located near the three part areas. In order to reduce the number of variables involved, only one port location, Southern California, was considered. Three plant locations were considered in order to obtain three data points for each system. The specific costs investigated were limited to:

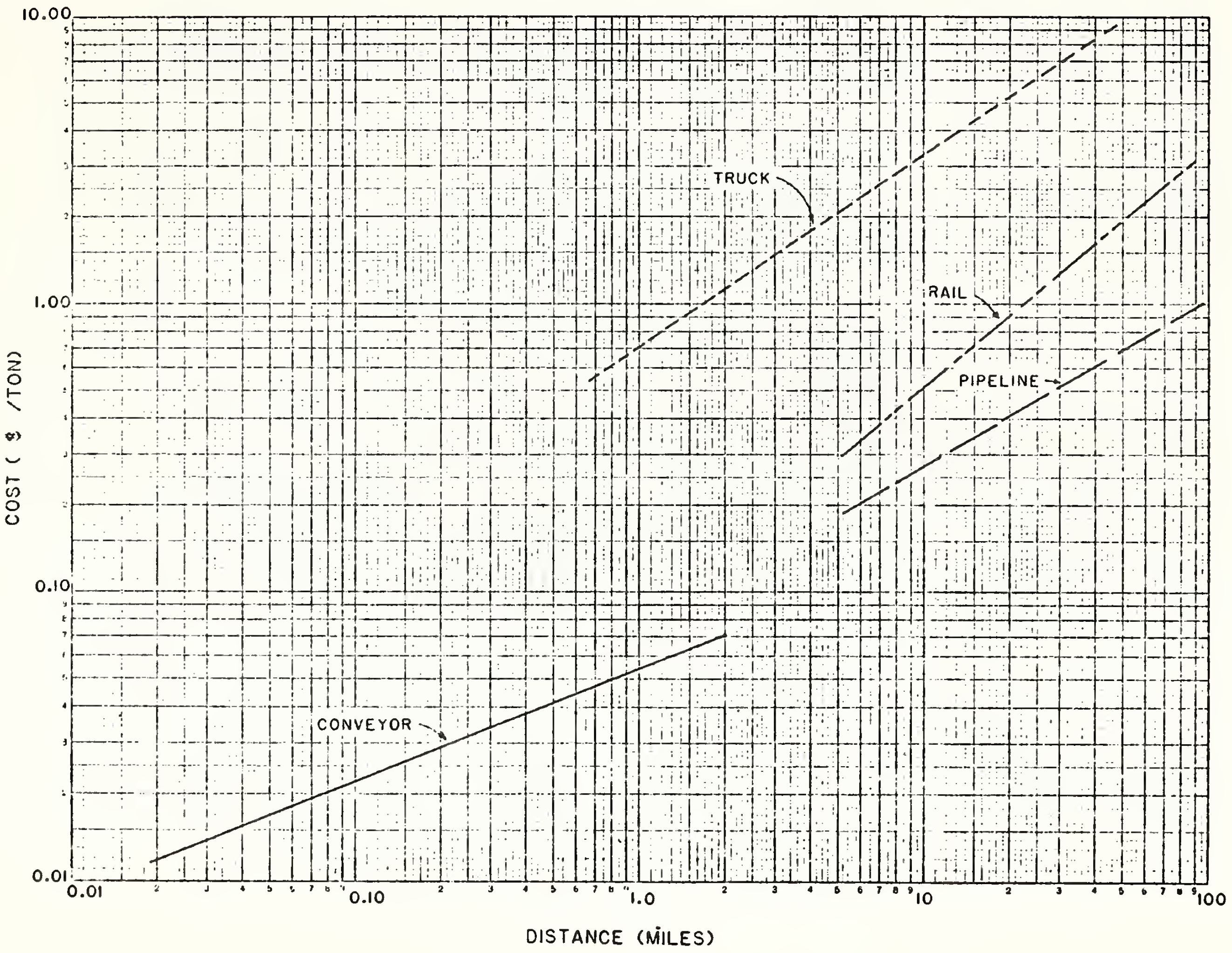
Equipment Cost
Installation Cost
Energy Cost
Maintenance Cost
Operation Cost

Figure 4.1 presents the results of the economic study for the 3-metal plant while Figure 4.2 presents the results for a 4-metal plant.

Inspection of Figures 4.1 and 4.2 indicates that except for very short haul distances, a slurry pipeline has a decided economic advantage over the other transport modes. For short distances, a conveyor system is most economical.

4.5.2 Potential Environmental Impacts and/or Legal Implications

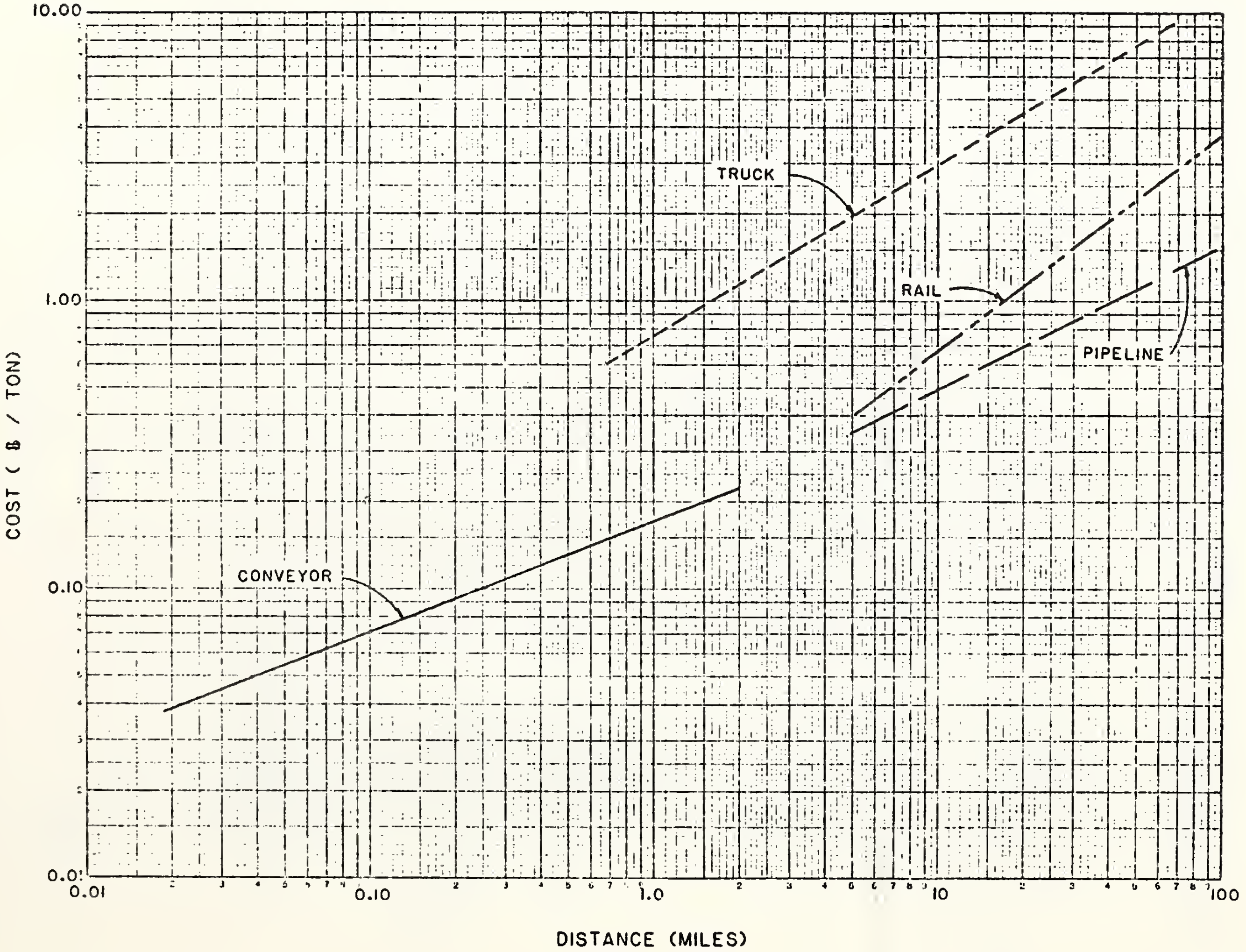
The potential environmental impacts associated with each mode of transportation were studied in general terms. The results of this evaluation are presented in Table 4.6.



MATERIAL QUANTITY FOR TRUCK, RAIL AND CONVEYOR TRANSPORT MODES IS 3.92×10^6 SHORT TONS PER YEAR; THROUGHPUT FOR PIPELINE IS 2.48×10^6 SHORT TONS PER YEAR (WEIGHT OF SOLIDS).

Figure 4.1

ON-SHORE TRANSPORTATION COSTS RAW NODULE FORM OF ORE 3-METAL PLANT



MATERIAL QUANTITY FOR TRUCK, RAIL AND CONVEYOR TRANSPORT MODES IS 1.18 X 10^6 SHORT TONS PER YEAR; THROUGHPUT PIPELINE IS 0.74 X 10^6 SHORT TONS PER YEAR (WEIGHT OF SOLIDS).

Firure 4.2

ON-SHORE TRANSPORTATION COSTS RAW NODULE FORM OF ORE 4-METAL PLANT

TABLE 4.6

POTENTIAL ENVIRONMENTAL IMPACTS OF LAND TRANSPORT MODES

Potential Impact	Ranking of Impact			
	Rail System	Conveyor	Slurry Pipeline	Truck System
Air Pollution (Particulates)	Moderate	Slight	None	Moderate
Water Pollution	None	None	None	None
Construction Impacts	None*	Slight	Slight	None
Traffic	Moderate	None	None	Great
Noise	Moderate	Moderate	None	Moderate
Recreation	Slight	None	None	Slight
Wildlife	Slight	Slight	None	Slight
Agriculture	None*	Slight	None	Slight

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*Neglects new track construction; slight-to-moderate impact possible with new track construction in certain areas.

NOTE: The above does not include impacts due to accidental spills caused by train derailment, pipeline rupture, etc. since the route is unknown.

From Table 4.6 it is concluded that a slurry pipeline has the least potential environmental impact followed by conveyor, rail and then truck. This assessment agrees with previous reports on the subject. As an example, the Federal Energy Administration Project Independence final task force report in discussing coal slurry pipelines, states the following:

> "...once installed, the pipeline is silent, invisible, does not constitute a barrier to wildlife, water flow or people movement, and does not interfere with agriculture, recreation or any other land uses. Coal slurry pipeline poses minimal safety hazard, even less than oil or gas pipeline since the slurry is not explosive or even flammable without dewatering. Unless the pipe ruptures violently, with the possibility of mechanical damage to nearby people or structures, a coal slurry pipeline leak would result in the discharge of the relatively inert coal-water mixture which is fairly easy to control and clean up."

This discussion of coal slurry pipelines holds equally true for any buried pipeline transporting an inert material such as manganese nodule ore.

Legal constraints per se, would not affect the choice of system except that all modes must provide protection against releasing dust or spills of slurry in violation of air and water quality standards. Such protection can be provided fairly easily.

4.5.3 Safety Considerations

A risk analysis for rail, truck and slurry pipeline was carried out assuming a 161 kilometer (100-mile) haul distance and a 3-metal plant (Brobst, 1972). The results of this study are directly proportional to the haul distance therefore, if shorter hauls are assumed, the magnitude of the results will change but the relative ranking will not. The results of the study indicate that a slurry pipeline can be expected to have two failures over a twenty year period and the rail system can be expected to experience seven accidents in twenty years. By comparison, a truck haul system can be expected to have more than 500 accidents over a twenty year period.

Loss of life due to a slurry pipeline rupture would be remote. Loss of life in connection with the rail system accidents is possible but of low probability. Loss of life in conncection with truck accidents is to be expected and would be on the order of one per year for the 161 kilometer (100-mile) haul.

4.6 IDENTIFICATION OF MOST LIKELY RAW NODULES TRANSPORT SYSTEM

The four transport systems considered for transporting raw nodules were: rail, slurry pipeline, truck and conveyor. Slurry pipeline proved more economical for haul distances from about 3.2 kilometers (2 miles) up to 161 kilometers (100 miles) as considered in the study. It also demonstrates environmental and safety advantages. Truck haul can be eliminated mainly on the basis of cost and adverse safety and environmental effects. Rail systems can be eliminated mainly on economic reasons. A conveyor system is most economical for short haul distances; up to about 3.2 kilometers (2 miles). However, the practicality of a conveyor system is questionable, particularly in developed areas such as those in the vicinity of West Coast ports suitable for ore transports. The anticipated conditions would require that the conveyor jog around existing structures and cross streets and utilities. This would prove difficult to construct, operate and maintain. Thus, it is probable that industry would select pipeline transport even for very short distances. For very short hauls, the nodules could be transported hydraulically without first crushing the raw nodules.

4.6.1 Description of Most Likely System

4.6.1.1 Design Assumptions

A conceptual design of the slurry transport system was prepared to obtain approximate component sizes to establish costs and resources required for this system. The assumptions used to arrive at the design are as follows:

Throughput - 2.2×10^6 mtpy (2.5×10^6 tpy) of dry solids
(3-metal plant)
0.7×10^6 mtpy (0.5×10^6 tpy) of dry solids
(4-metal plant)
Pipeline Operation - 315 days per year (15 days less than the mining operation to allow for downtime)
Specific Gravity of Solids - 3.2
Grinding to take place at the port area.
Gradation - Minus 200 mesh
Concentration - 45 percent solids by weight
Plant Location - Various distances from port but no elevation head (flat terrain).

The results of the slurry pipeline analysis are presented in Table 4.7.

TABLE 4.7

CHARACTERISTICS OF SLURRY PIPELINE

	3-Metal Plant	4-Metal Plant
Pipe Size	25 cm (10 in.)	15 cm (6 in.)
Transport Velocity	2.7 m/sec (9 fps)	2.1 m/sec (7 fps)
Discharge Rate	8.3 m^3/min (2200 gpm)	2.3 m^3/min (600 gpm)
Friction Head	2.6 meters per 100 meters	2.7 meters per 100 meters

The system was described in Paragraph 4.4.4 and will not be repeated here. Certain aspects of the system not previously discussed are as follows:

4.6.1.2 Water Supply

Water requirements for the systems are about 2,700,000 cubic meters (2200 acre-feet) per year for a 3-metal plant and 810,000 cubic meters (660 acre-feet) per year for a 4-metal plant. As a comparison, these amounts are approximately equal to the average annual consumption for 8600 households and 2600 households respectively.

Since the nodules contain salts, the slurry will be corrosive regardless of the quality of the water used to transport them. It is probable, therefore, that sea water will be used as the water supply.

4.6.1.3 Resource Requirements

The resource requirements for the slurry system are present in Table 4.8.

TABLE 4.8

SLURRY PIPELINE RESOURCE REQUIREMENTS

Resource	3-Metal Plant	4-Metal Plant
Land for Pipeline	3.8 hectares per km (6 acres per mile)	same
Land per Station Pump	0.8 hectares (2 acres)	same
Land for Ore Storage Pond 1	4 hectares (10 acres)	1.6 hectares (4 acres)
Water Required	2.7×10^6 m^3/yr (2200 acre-feet/yr)	0.8×10^6 m^3/yr (660 acre-feet/yr)
Manpower	6-12 man years/year	same
Energy Requirements	2.	2.
Equipment	3.	3.

Notes 1. Includes area required for dike.
2. See Figure 4.3.
3. Standard items, no significant impact on manufactures.

4.6.1.4 Potential Environmental Concerns

As previously discussed, the potential environmental impacts associated with a slurry pipeline are relatively slight. The main concerns are:

1. Construction Impacts. The impacts during construction consist of dust pollution, traffic disturbance at road crossings, disturbance to existing vegetation and community impact where construction must take place in urban areas such as in the port area. These are all short term impacts and minimal in intensity for a small diameter pipeline. Mitigative measures such as sprinkling for dust control, constructing road crossings during off-peak traffic hours and revegetating the pipeline route would minimize the construction impacts.

2. Pipeline Rupture. A pipeline rupture is an extremely unlikely occurrence. Such a rupture would be discovered very quickly by the pipeline instrumentation and the system could be shutdown before any significant volume of material was spilled.

3. Disposal of Water. The transport water will probably be sea water but even if fresh water is used it will be contaminated with salts contained by the nodules. Thus, this water must be recycled, returned to the sea or treated before being discharged on land.

4.7 TRANSPORT OF DRY GROUND ORE

If ore is delivered to the port in the dry ground form, the following modes of on-shore transportation are considered possible: rail system;

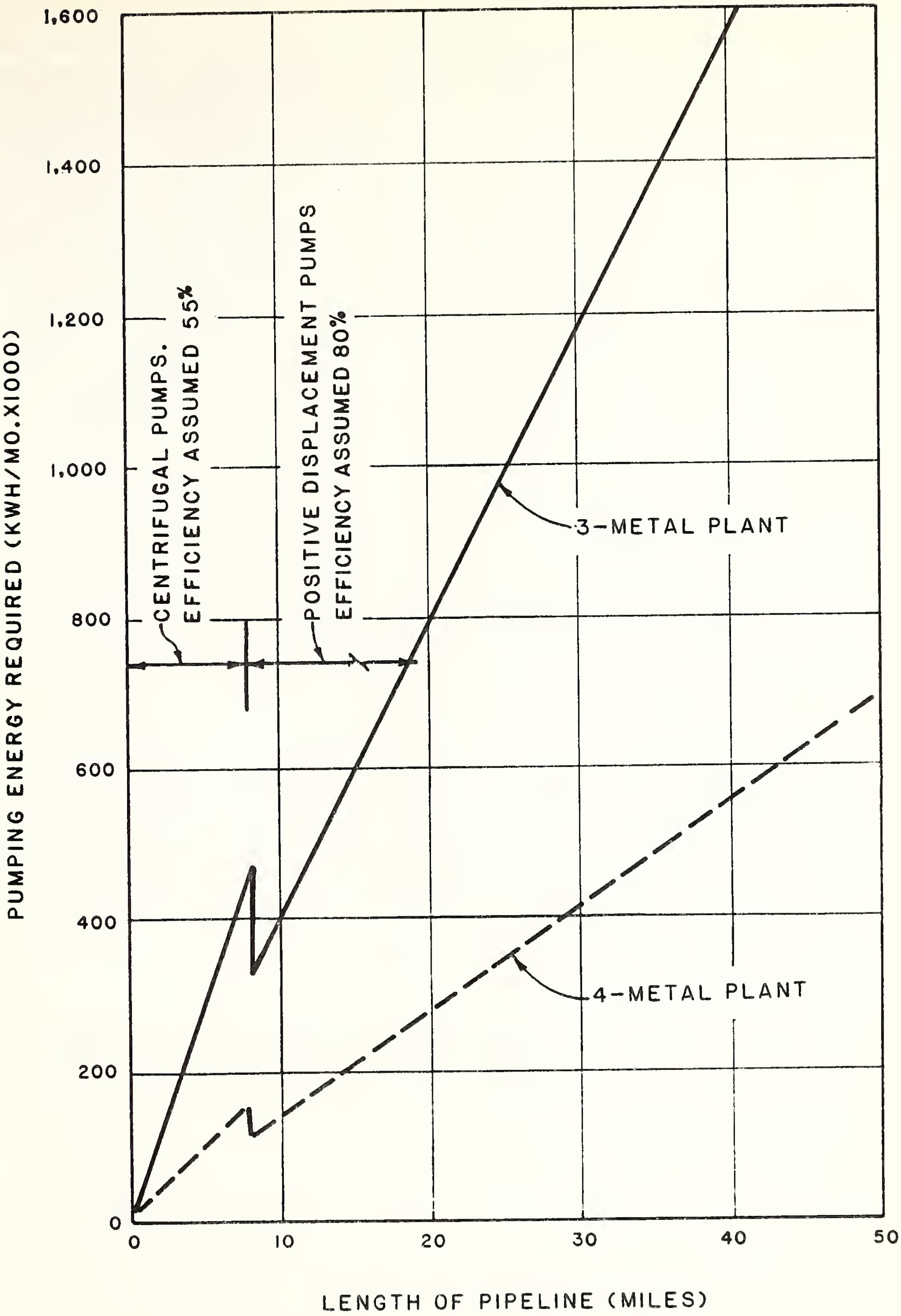


Figure 4.3 **SLURRY PIPELINE ENERGY REQUIREMENTS**

truck haulage and conveyor system. A slurry pipeline was not considered since: (a) this would require slurrying of the dry ore at the port and redrying it at the plant for three of the five processing techniques; and (b) such a system would be virtually identical, except for grinding, to the slurry pipeline system for raw nodules (See 4.4.4). This double drying requirement would result in a significant increase in energy requirements and, therefore, in operating cost. Pneumatic transport for short haul distances, less than 8 kilometers (5 miles), was considered. However, discussions with manufacturers of penumatic conveying equipment indicated that multiple systems would be required to transport the anticipated tonnages. It was also determined that energy requirements would be very high. Based on these findings and on "ballpark" cost figures provided by the manufacturers, it was determined that total cost of such a system would be significantly higher than a conveyor system. It also appears that this application is on the fringe of existing technology. This mode was therefore eliminated from consideration.

The sea transport study presented in Section 3.0 concluded that delivery of dry ground ore was likely only for the Gulf Coast port. Thus, the study to determine the most likely mode of land transportation has fewer options to consider than the study performed for the raw nodules. The remainder of the analysis of rail, truck and conveyor haulage of dry ground ore, however, is identical to the analysis performed for raw nodules. The conclusions reached for the dry ground ore will therefore be based on the data and discussion previously presented for the raw nodule form of ore.

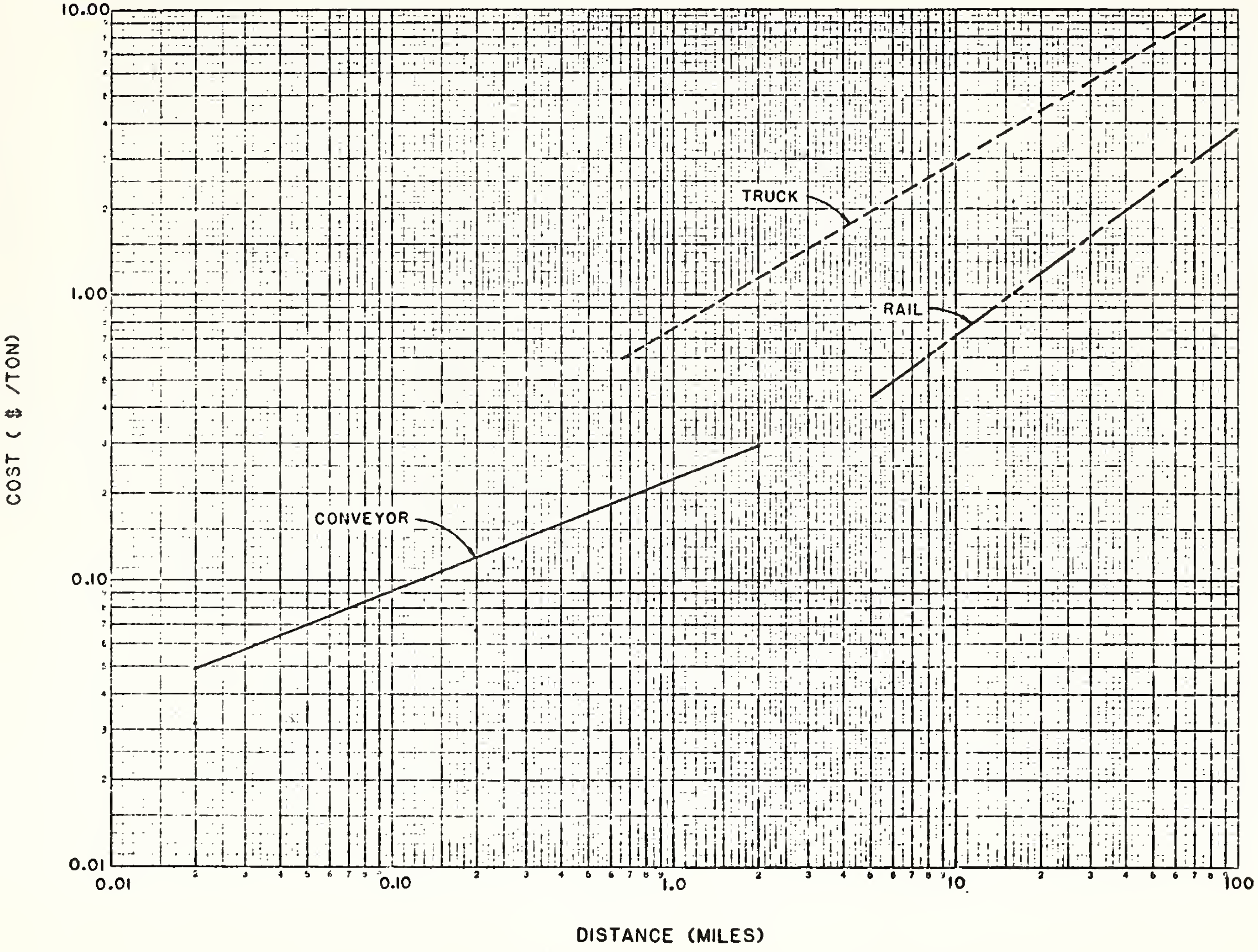
4.7.1 Identification of Most Likely Transport - Dry Ground Ore

Based on the results of the comparative study reported in Section 4.5, and the economic analyses presented in Figures 4.4 and 4.5, two most likely modes of transport are indicated. For haul distances up to about 8 kilometers (5 miles), conveyor transport is considered to be most likely while for longer haul distances, rail haulage is most likely.

4.7.2 Description of Most Likely Systems

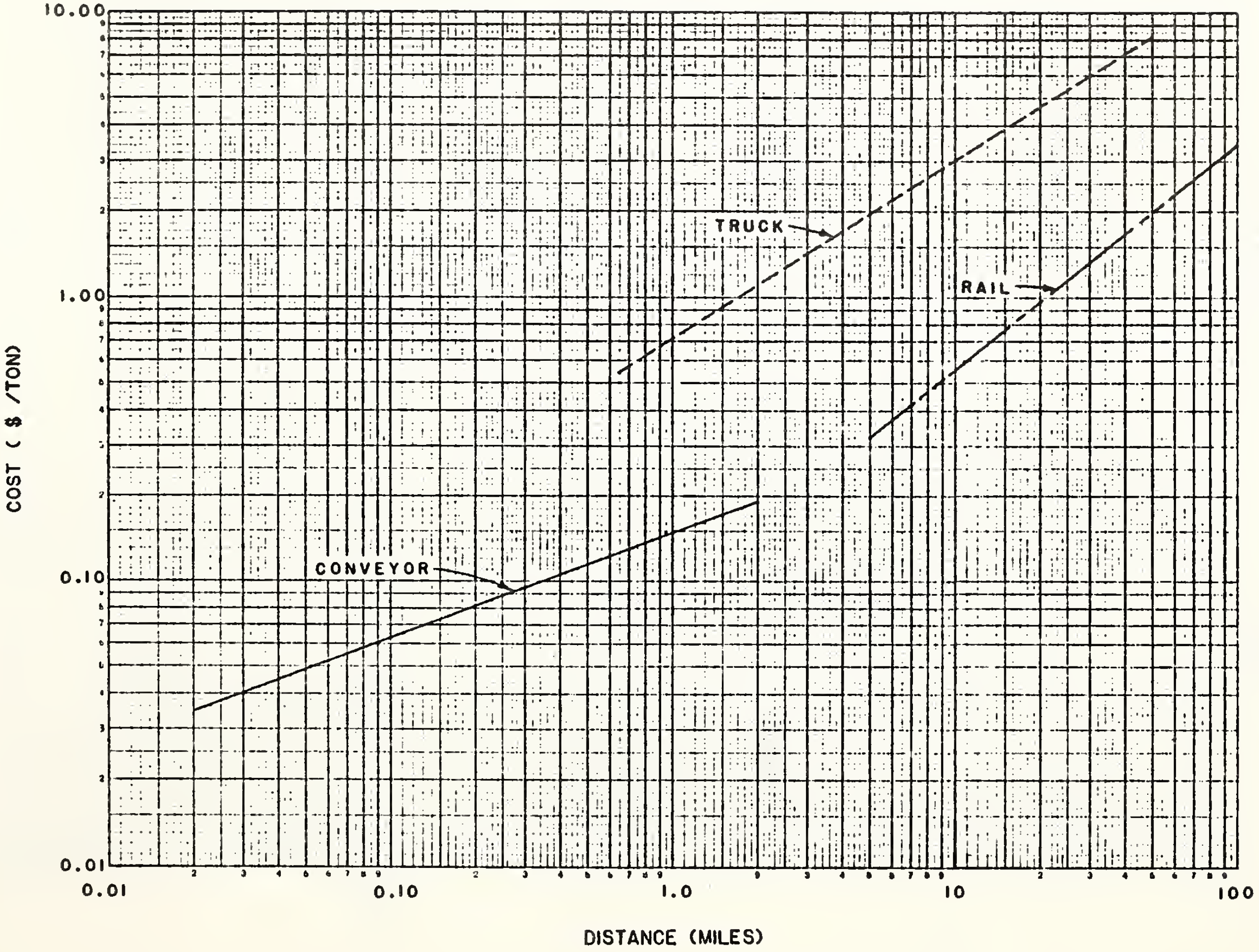
4.7.2.1 Conveyor Transport

The conveyor transport system was described previously in Paragraph 4.4.3. The resource requirements associated with this system are presented in Tables 4.9 and 4.10.



MATERIAL QUANTITY FOR TRUCK, RAIL AND CONVEYOR TRANSPORT MODES IS 0.87 X 10^6 SHORT TONS PER YEAR.

Figure 4.4
ON-SHORE TRANSPORTATION COSTS DRY POWDER FORM OF ORE 4-METAL PLANT



MATERIAL QUANTITY FOR TRUCK, RAIL AND CONVEYOR TRANSPORT MODES IS 2.9 X 10^6 SHORT TONS PER YEAR.

Figure 4.5

ON-SHORE TRANSPORTATION COSTS DRY POWDER FORM OF ORE 3-METAL PLANT

TABLE 4.9

RESOURCE REQUIREMENTS FOR CONVEYOR

4-METAL PLANT

Resource	Quantity
Land Required for Conveyor	3.2 hectares per km (6 acres per mile)
Land Required for Unloading Stockpile	1.6 hectares (4 acres)
Manpower Required	6 man years/year for 3050 meters (10,000 foot) length
Energy Requirements	4,250,000 kwh per year for 3050 meters (10,000 foot) length
Configuration	61 cm (24-inch) wide belt, totally enclosed for dust control
Equipment	Standard items, no significant impact on manufacturers

TABLE 4.10

RESOURCE REQUIREMENTS FOR CONVEYOR

3-METAL PLANT

Resource	Quantity
Land Required for Conveyor	3.2 hectares per km (6 acres per mile)
Land Required for Unloading Stockpile	4.8 hectares (12 acres)
Manpower Required	man years/year for 3050 meters (10,000 foot) length
Energy Requirements	4,300,000 kwh per year for 3050 meters (10,000 foot) length
Configuration	76 cm (30-inch) wide belt, totally enclosed for dust control
Equipment	Standard items, no significant impact on manufacturers

The potential environmental concerns associated with conveyor transport of ore can be summarized as follows:

1. Air Pollution. The dry ground manganese ore would be very susceptible to dusting. The impacts from air pollution due to dusting can be alleviated for the most part by designing a conveyor system with hoods and providing minimum belt speeds which would reduce dusting. Also, the use of low-head chute transfers, where the distance between belt transfers is minimal, would provide means for alleviating dusting.

2. Construction Impacts. Construction impacts would consist of dust pollution, possible traffic disturbance in community areas and possible vegetative disturbance. These impacts would be of short-term duration. Sprinkling for dust control, constructing road crossings during periods of little or no traffic and revegetating areas disturbed by construction would serve to minimize the construction impacts.

3. Noise Impact. A conveyor system will generate noise during its operation. However, if the conveyor route is in a sparsely populated area, the noise impact would be minimal. Noise during construction and installation of a conveyor system would be a short-term impact.

4. Aesthetic Impact. The installation of a conveyor system would be a visual impact along its route. However, if installation of a conveyor system was to be in a sparsely populated area and somewhat masked by existing topography, the impact would be minimal.

4.7.2.2 Rail System

The rail haul system for transporting dry ground ore would consist of the following:

Locomotives. Locomotives would be the same as discussed in Paragraph 4.4.1.

Freight Cars. Hopper cars of 90 tonnes (100 ton) capacity were assumed. The cars will be covered in order to control dust loss to the atmosphere.

Loading and Unloading. The material would be recovered from storage silos and loaded into the cars by an over-track hopper. The entire system would be sealed for dust control. Likewise, unloading would be by a completely sealed system for rail to storage facility.

The rail system equipment required to transport dry ground ore is presented in Table 4.11.

TABLE 4.11

RAIL TRANSPORT EQUIPMENT REQUIRED FOR DRY GROUND ORE

4-METAL PLANT (3-METAL PLANT)

Distance Plant-to-Port in Kilometers (Miles)	Locomotive Per Unit Train	Rail Cars Per Unit Train	Number of Trains Required
8 (5)	1 (1)	4 (15)	1 (1)
80 (50)	2 (3)	27 (44)	1 (2)
161 (100)	2 (3)	27 (44)	1 (2)

The resource requirements associated with this system are presented in Tables 4.12 and 4.13.

TABLE 4.12

RESOURCE REQUIREMENTS - RAIL TRANSPORT OF DRY GROUND ORE

4-METAL PLANT

Fuel Consumption:			
	8 km (5-mile) haul	0.58 m^3/day	(154 gpd)
	80 km (50-mile) haul	5.0 m^3/day	(1330 gpd)
	161 km (100-mile) haul	10.1 m^3/day	(2660 gpd)
Manpower:			
	8 km (5-mile) haul	12 man years/year	
	80 km (50-mile) haul	16 man years/year	
	161 km (100-mile) haul	16 man years/year	
Equipment:		Readily Available	

TABLE 4.13

RESOURCE REQUIREMENTS - RAIL TRANSPORT OF DRY GROUND ORE

3-METAL PLANT

Fuel Consumption:			
	8 km (5-mile) haul	1.69 m^3/day	(446 gpd)
	80 km (50-mile) haul	16.22 m^3/day	(4280 gpd)
	161 km (100-mile) haul	32.43 m^3/day	(8560 gpd)
Manpower:			
	8 km (5-mile) haul	15 man years/year	
	80 km (50-mile) haul	30 man years/year	
	161 km (100-mile) haul	30 man year/year	
Equipment:		Readily Available	

The potential environmental concerns would consist of: air pollution; noise; traffic interruption and community impacts. None of these are considered to be serious for the size of trains required.

5.0 DISPOSAL OF PROCESS WASTES

5.1 BACKGROUND

5.1.1 Introduction

The disposal of wastes resulting from processing of ore is a major problem confronting the mineral industry. In the United States alone, the mineral industry annually discards approximately 1.55 billion tonnes (1.7 billion tons) of solid waste material, 40 percent of which is fine-sized material (tailings) requiring containment to prevent air and water pollution. The total accumulation of solid mining wastes is nearly 23 billion tonnes (25 billion tons), and these wastes cover approximately 0.8 million hectares (2 million acres) of land (Dean and Shirts, 1975). Tailings alone are accumulating at a rate of approximately 10,400 hectares (26,000 acres) per year (Shirts and Billbray, 1976).

Depending on the extractive process, the rate of nodule mining and the form of waste disposal, wastes from a nodule processing plant would accumulate at a rate of from 4 (10)[1] to 40 hectares (100)[2] acres per year assuming a 12.2 meter (40-foot) depth. That is, the land impact of disposal of the wastes resulting from a single processing plant would be less than 1/2 of 1 percent of the total land utilized each year in the United States for disposal of mill tailings.

5.1.2 Types of Process Wastes

Generally, the largest portion of mineral process wastes consists of finely ground rock slurried with liquid wastes. This heterogeneous mixture is referred to as "tailings" in the mining industry. The ground rock is what is left after the value metals have been removed. The texture of tailings ranges from fine sand to clay, depending on the character of the ore, the extent of physical abrasion in process, and the chemicals used to extract the value metals.

The liquid which is used to slurry the solids usually contains substantial quantities of dissolved chemicals, soluble solids, and collodial particulates. The liquids are normally considered as part of the process wastes, although they sometimes are recycled after appropriate treatment.

Other process wastes may include dry solids such as slag; ash from coal burning; gaseous scrubber residue; solid chemical process materials such as gypsum; and the like. Except for slag, all of these are usually slurried and transported with the tailings to the disposal site.

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[1] Four-metal plant when wastes are dried.
[2] Three-metal plant with slurried wastes.

5.1.3 Usual Practice for Disposing of Process Wastes

The most common way of disposing of tailings and other process wastes is in slurry form behind an earth embankment. The reservoir behind the embankment is sealed to prevent contamination of the environment. The slurry transport liquids are either allowed to evaporate or are decanted and recycled, or both. Such a tailings disposal system is described in greater detail in later sections of this chapter.

Alternative process waste disposal methods used by the mining industry are dependent on character of wastes. That is, tailings slurry can only be placed in a tailings reservoir because of its fluid character. However, if wastes are produced in a dry solid form and are innocuous, then a landfill disposal scheme may be implemented or the wastes may be sold. For instance, granulated slag can make suitable fill or ballast, and gypsum and lime wastes are sometimes sold and used as soil additives.

5.2 POTENTIAL METHODS OF WASTE DISPOSAL

5.2.1 Alternatives Considered

Six disposal systems were described by NOAA as having been mentioned for potential use in the industry. Possible ranges in distance between port, plant, and waste disposal sites were also specified. These disposal methods are summarized as follows:

a) Spreading of dry or nearly dry waste over a land disposal area, either in piles or layers, when the area is adjacent to the plant and at three different distances from the plant;

b) Burial of dry or nearly dry waste in a landfill (that is, with alternating layers of waste and cover material) when the landfill is adjacent to the plant and at three different distances from the plant;

c) Use of the waste in dry or nearly dry form as cover material in a municipal sanitary landfill when the landfill is at three different distances from the plant;

d) Use of conventional tailings disposal system for disposal of the waste in a slurry form and for evaporation of the liquid component when the disposal area is adjacent to the plant and at a distance of 5 miles or more from the plant.

e) Storage adjacent to the plant as a manganese reserve for further processing in the future; and

f) Ocean dumping when the plant is located adjacent to the port and when the plant is located 5 miles or more inland from the port.

5.2.2 Purpose and Scope of This Section

The purpose of waste disposal analysis is to describe the physical operations and the physical requirements (e.g. land, power, water, personnel, etc.) involved in the use of these various alternatives. However, it was recognized by NOAA that some of the options could perhaps be eliminated or restricted to only certain types of waste forms. Accordingly, the technical and legal feasibility and the relative economics, where appropriate, were evaluated to determine which alternatives could be eliminated from detailed consideration. Thus, only those alternative which appeared technically feasible and which appeared to meet all current legal restraints were subjected to detailed analysis.

5.3 CHARACTERIZATION OF PROCESS WASTES

5.3.1 Description of Wastes Produced by Each Process

The wastes from the five alternative processes would in most cases consist predominantly of hydrous slimes[1] and settleable sludges with lesser amounts of ash, scrubber solids, lime boil solids, and other minor constituents. The notable exceptions are in the smelting process where the wastes would predominantly be granulated slag and in the hydrochloric acid leach process where approximately 1/3 of the solid wastes would be in the form of fused salts.

A more thorough discussion of the types and quantities of wastes which would be produced by each of the five process routes are described in detail in Chapters 4.0 through 8.0 of Volume I. A summary of the quantities and chemical and physical characteristics of the wastes for each process are presented in Tables 5.1 through 5.5.

5.3.2 Waste Treatment Alternatives

Treatment of wastes prior to disposal was analyzed in the Phase IA in order to evaluate operations which might be necessary for use of some of the waste disposal methods. The treatment methods, which are described in Volumes I and III, include:

1) Precipitation of soluble toxic elements with direct discharge of treated wastes;

2) Precipitation of soluble toxic elements followed by washing of solid waste to remove soluble innocuous and toxic elements for separate discharge; and

3) Precipitation of soluble toxic elements followed by washing to remove remaining solids and drying of solid wastes for disposal.

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[1] Hydrous slimes are hydroscopic and retain water for indefinite periods of time. Some of these may never become "solidified".

TABLE 5.1

CHARACTERIZATION OF SOLID AND LIQUID WASTES REDUCTION/AMMONIA LEACH PROCESS

STREAM		TANK HOUSE PURGES	LIX SECTION CRUD	SPENT CARBON	LEACHED TAILS	LIME BOIL SOLIDS	WATER HARDNESS SOLIDS	GASIFICATION ASH (slag)	COMBUSTION ASH	OFFGAS SCURBBER SOLIDS
Solid Flows	mtpd	2.2	0.11	0.11	7,400	56	7.7	130	36	65
	tpd	2.4	0.12	0.12	8,200	62	8.5	144	40	72
Liquid Flows	m^3/hr				384	14	1	20		10
	gpm				1690	62	4	90		45
Temperature	°C/°F	25/77	40/104	25/77	50/122	50/122	25/77	80/176	90/194	75/167
Constituents:		. Lead . Lead Sulfate . Manganeae Dioxide . Etc.	. UNK	. Carbon	. Manganese Dioxide . Manganese Monoxide . Magnanese Carbonate . Iron Hydroxide . Clays . Ammonia . Carbon Dioxide . Copper . Nickel . Cobalt . Zinc . Molybdenum . Sea Salt	. Gypsum . Aluminum Oxide . Molybdenum . Sea Salt . Magnesium . Sodium . Boric Acid . Cobalt	. Limestone . Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc.	. Calcium Sulfite . Calcium Sulfate . Silica . Aluminum Oxide . Manganese Dioxide . Manganeae Carbonate . Magnesium
Chemical Characteristics:		A			A, D	A, D, E	B, E	A, B	A, B	A, B, D, E
Physical Characteristics:		D			A, B	B	B	C		B

KEY:

	Chemical Characteristics		Physical Characteristics
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elementa	C	Vitreous Solids
D	Solutiona Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 5.2

CHARACTERIZATION OF SOLID AND LIQUID WASTES
CUPRION/AMMONIA LEACH PROCESS

STREAM		TANK HOUSE PURGES	LIX SECTION CRUD	SPENT CARBON	LEACHING TAILS	LIME BOIL SOLIDS	WATER HARDNESS SOLIDS	GASIFICATION ASH (slag)	COMBUSTION ASH	OFFGAS SCRUBBER SOLIDS
Solid Flows	mtpd	2.2	0.11	0.11	9,500	58	10	110	90	65
	tpd	2.4	0.12	0.12	10,500	64	11	120	100	72
Liquid Flows	m^3/hr				430	15	1.2	78		10
	gpm				1910	65	5.3	345		45
Temperature	°C/°F	25/77	40/104	25/77	50/122	50/122	25/77	30/86	90/194	55/131
Constituents:		. Lead . Lead Sulfate . Manganese Dioxide . Etc.	. UNK	. Carbon	. Manganese Dioxide . Manganese Oxide . Manganese Carbonate . Iron Hydroxide . Clays . Ammonia . Carbon Dioxide . Copper . Zinc . Cobalt . Nickel . Molybdenum . Sea Salt	. Gypsum . Silica . Aluminum Oxide . Nickel . Cobalt . Sea Salt . Magnesium . Sodium . Boric Acid	. Limestone . Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc.	. Calcium Sulfite . Calcium Sulfate . Silica . Aluminum Oxide . Manganese Dioxide . Manganese Carbonate . Magnesium
Chemical Characteristics:		A			A, C	A, C, D	B, D	A, B	A, B	A, B, C, D
Physical Characteristics:		D			A, B	B	B	C		B

KEY:

	CHEMICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 5.3

CHARACTERIZATION OF SOLID AND LIQUID WASTES
HIGH-TEMPERATURE SULFURIC ACID LEACH PROCESS

STREAM		TANK HOUSE PURGES	LIX SECTION CRUD	SPENT CARBON	LEACHED TAILS	LIME BOIL SOLIDS	WATER HARDNESS SOLIDS	COMBUS-TION ASH	OFFGAS SCRUBBER SOLIDS
Solid Flows	mtpd	2.3	0.22	0.11	9,500	1,700	8.5	90	34
	tpd	2.5	0.24	0.12	10,600	1,900	9.4	100	37
Liquid Flows	m^3/hr				394	65	0.4		5.7
	gpm				1730	290	1.8		25
Temperature $^{o}C/^{o}F$		25/77	40/104	25/77	30/86	50/122	25/77	90/194	45/113
Constituents:		. Lead . Lead Sulfate . Manganese Dioxide	. Unk	. Carbon	. Manganese Dioxide . Manganese Monoxide . Manganese Carbonate . Iron Oxide . Copper . Nickel Oxide . Zinc . Copper Oxide . Zinc Oxide . Sea Salt . Aluminum Oxide . Sodium Oxide . Magnesium . Ammonium . Sulfuric Acid . Sodium Cobalt	. Silica . Aluminum Oxide . Calcium Sulfate . Nickel . Cobalt	. Limestone . Silica . Aluminum Oxide . Etc.	. Silica . Aluminum Oxide . Etc	. Calcium Sulfate . Calcium Sulfite . Silica . Aluminum Oxide . Manganese Dioxide . Etc
Chemical Characteristics:		A			A, D	A, D	B, E	A	A, B
Physical Characterisitcs:		D			A, B	B	B		B

KEY:	CHEMICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 5.4

CHARACTERIZATION OF SOLID AND LIQUID WASTES REDUCTION/HYDROCHLORIC ACID LEACH PROCESS

STREAM		LEACHED TAILS	FUSED SALTS	COPPER TANK HOUSE PURGE	NICKEL TANK HOUSE PURGE	COPPER LIX CRUD	NICKEL LIX CRUD	GAS TREATMENT SOLIDS	LIME BOIL SOLIDS	WATER HARDNESS SOLIDS	COMBUS-TION ASH	SOLIDS FROM SULFURIC ACID PURGE
Solid Flows	mtpd	720	640	0.16	0.55	0.04	0.04	43	25	5.4	114	0.22
	tpd	800	700	0.18	0.60	0.04	0.04	48	28	6.0	125	0.24
Liquid Flows	m^3/hr	90						7	6	0.7		
	gpm	400						31	27	3		
Temperature	$^oC/^oF$	40/104	25/77	25/77	25/77	40/104	40/104	45/113	110/230	25/77	90/194	40/104
Constituents:		. Clays . Ferrous Hydroxide . Aluminum Hydroxide	. Salts	. Lead . Lead Sulfate . Manganese Dioxide	. (?)	. UNK	. UNK	. Magnesium	. Gypsum . Silica . Aluminum Oxide . Etc	. Limestone . Silica . Aluminum Oxide . Etc	. Silica . Aluminum Oxide . Etc	. Nodule Dust
Chemcial Characteristics:		A, D	C	A	A			A,B,D,E	A,B, D, E	B, E	A, B	
Physical Characteristics:		A, B	E	D	D			B	B	B		D

KEY:

	CHEMICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

TABLE 5.5

CHARACTERIZATION OF SOLID AND LIQUID WASTES SMELTING PROCESS

STREAM		TANK HOUSE PURGES	LIX SECTION CRUD	SPENT CARBON	LEACHED TAILS & GYPSUM	NEUTR. pptd SOLIDS	LIME BOIL SOLIDS	GRANU-LATED SLAG	GASIFICA-TION ASH (Slag)	COMBUS-TION ASH	WATER HARDNESS SOLIDS	OFFGAS SCRUBBER SOLIDS	SMELTING DUST
Solid Flows	mtpd	0.33	0.05	0.11	20	9	190	1600	39	13	2.5	26	0/174
	tpd	0.36	0.06	0.12	22	10	210	1760	43	14	2.7	29	0/191
Liquid Flows	m^3/hr				1.1	1.5	5.5	17	17		0.3	4.6	
	gpm				5	6.8	24	73	75		1.5	20	
Temperature $^{o}C/^{o}F$		25/77	25/77	25/77	50/132	40/104	50/132	40/104	80/176	90/194	25/77	75/165	40/104
Constituents:		. Lead . Lead Sulfate . Etc	. UNK	. Carbon	. Gypsum . Silica . Aluminum Oxide . Copper Sulfide . Sulfuric Acid . Nickel . Iron . Cobalt . Nickel Sulfide . Copper	. Iron Hydroxide . Magnesium Hydroxide . Manganese Hydroxide . Copper . Nickel . Cobalt . Ammonia	. Gypsum . Silica . Aluminum Oxide . Copper . Nickel . Cobalt . Magnesium . Sodium . Boric Acid . Ammonium	. Manganese Oxide . Magnesium . Manganese . Sodium . Iron Oxide . Boric Acid . Aluminum Oxide . Calcium Oxide . Sulfuric Acid . Silica . Copper . Nickel	. Silica . Aluminum Oxide . Etc	. Silica . Limestone . Aluminum Oxide . Etc	. Limestone . Silica . Aluminum Oxide . Etc	. Calcium Sulfate . Carbon Sulfite . Silica . Aluminum Oxide . Manganese Oxide . Manganese Dioxide	. Manganese Oxide . Manganese . Iron . Iron Oxide . Zinc . Lead . Etc
Chemical Characteristics:		A			A, D	A, D	A, D	A, D, E	A,B,D,E	A, B	B, E	A,B,D,E	A
Physical Characteristics:		D			B	A, B	B	C	C		B	B	D

KEY:

	CHEMICAL CHARACTERISTICS		PHYSICAL CHARACTERISTICS
A	Solids Containing Fixed Toxic Elements	A	Hydrous Slimes
B	Inert Solids	B	Settleable Sludges
C	Soluble Solids with Toxic Elements	C	Vitreous Solids
D	Solutions Containing Toxic Elements	D	Inert Solids
E	Solutions Containing Innocuous Compounds	E	Soluble Solids

The purpose of evaluating waste treatment is to determine if and how the wastes can be made less "hazardous" or less "toxic"; or alternately, "more disposable". Such treatment may be necessary for alternatives such as landfill and ocean dumping to be viable; however, the evaluation of the need for treatment or not would depend on the actual characteristics of industry wastes, which are currently unknown. In light of present and proposed legislation, all of the process wastes except slag would require disposal in reservoirs or areas with naturally impermeable soil or rock underlying the site or in lined disposal areas.

The waste treatment study has shown that waste treatment to permit more disposal options appears technically feasible, although potentially expensive. Drying of the wastes so that they could be placed in a landfill is also feasible; although the latter would be costly. Therefore alternative disposal methods such as landfill and ocean dumping have been considered in this analysis of possible methods of nodule processing waste disposal.

5.4 LEGISLATION CONTROLLING WASTE DISPOSAL

Until the passage of the first environmental legislation in the late 1960's and the disastrous failure of the solid waste disposal facility at Buffalo Creek, West Virginia in 1972, relatively little governmental effort was expended regulating solid waste disposal in the mineral industry. However, as the result of recent environmental concerns associated with solid waste disposal facilities and concerns for public safety, there are now several federal laws and regulations which govern waste disposal.

Four principal federal environmental laws now regulate mine and mill waste disposal. These are PL92-500, Federal Water Pollution Control Act; PL93-253, Safe Drinking Water Act; PL94-580, Resource Conservation and Recovery Act; and PL93-319, Clean Air Act. From each of these laws, federal regulations are developed to implement the laws and to define those steps or measures necessary to comply with these laws. All of these laws require a permit for discharging into the environment. The states may assume the permitting responsibility within EPA guidelines. Some states including Texas, California, and Connecticut have more stringent solid waste disposal regulations, especially for hazardous waste, than the national EPA regulations (Rouse, 1977). However, it is beyond the scope of this study to discuss state laws.

There is also a Federal law, the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532), under which a permit is required to transport material from the United States to sea for dumping.

In addition to these EPA-administered laws and regulations, the Mining Enforcement and Safety Administration (MESA) requires that impounding tailings structures meet certain hydrological and stability requirements. The MESA regulations for metal and non-metal waste disposal facilities are now being written and will be published as Code of Federal Regulations, Part 30, Section 60, when completed (Ferriter and Fugimoto, 1977).

A brief description of each of the environmental laws, as it applies to solid mineral waste disposal, is presented below.

5.4.1 Federal Water Pollution Control Act (PL92-500)

The Federal Water Pollution Control Act regulates effluent discharge into surface waters. Existing mine and mill discharges must be neutral in pH and contain no toxic or hazardous substances. Proposed mines and mills will be required to use best practicable control technology currently available to obtain zero discharge of pollutants (Environmental Protection Agency, 1975a). By 1985, this could require a closed system with no discharge into the environment.

PL92-500, Section 3.11, "Oil and Hazardous Substances Liability," requires a contingency plan for possible spill of hazardous substances in harmful quantities (Environmental Protection Agency, 1975b). Oil is the only hazardous substance for which Section 3.11 is now enforced. However, the EPA desires to expand enforcement to include other hazardous substances, so a contingency plan for possible spills from waste disposal would be required in the future (Rouse, 1977).

5.4.2 Safe Drinking Water Act (PL92-253)

The Safe Drinking Water Act protects public drinking water supplies. Part C, "Protection of Underground Sources of Drinking Water," is pertinent in its application to contamination of underground aquifers. EPA-proposed regulations (Environmental Protection Agency, 1976) state that underground injection includes any contaminant which may be put below ground level and moves from the point of introduction. Seepage from waste disposal must not pollute sources of underground water supply.

5.4.3 Resource Conservation and Recovery Act (PL94-580)

The Resource Conservation and Recovery Act was passed October 31, 1976. Regulations should appear within 18 months of that date, and the law will apply to all existing and proposed waste disposal facilities. The law is extremely comprehensive, essentially covering all environmental concerns related to solid waste disposal and land use that are not covered by existing laws.

The law states that hazardous waste must be kept together whenever possible; inventoried; monitored; not allowed to escape into the air, water or environment; and be placed in a form easily retrievable for reprocessing to recover additional minerals. Definition of hazardous waste will be published in the regulations, but mine and mill waste would in all likelihood be considered hazardous. This act has far-reaching consequences for the mining and milling industries (Rouse, 1977).

5.4.4 Clean Air Act (PL93-319)

The Clean Air Act can also apply to mine waste disposal. Ambient air quality standards for particulates would have to be maintained and dust could not cause significant degradation of air quality. This has not been as crucial a problem to mine waste disposal as the other laws, although the extremely fine character of the wastes produced by the manganese nodule processing might well give rise to dust problems under some conditions.

5.4.5 Marine Protection, Research, and Sanctuaries Act (PL 92-532)

PL 92-532, commonly called the "Ocean Dumping Act", declares that it is the policy of the United States to regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare, or ammenities, or the marine environment, ecological systems, or economic potentialities.

An EPA permit, issued in consultation with NOAA, is needed to transport industrial wastes from the United States for dumping.

5.5 DISPOSAL ALTERNATIVE A, SPREADING WASTE OVER LAND DISPOSAL AREA

5.5.1 Description of Method

This disposal method consists of spreading dry or nearly dry process wastes over vacant land areas. The waste would either be placed in layers or stacked in piles. Conventional earth-moving equipment could be used for this type of operation, and no new technologies would be required. The description implies that no special regard be given to containing the dry waste to prevent surface erosion due to wind or water or to control leachate that might be formed from water percolating through the waste.

This waste disposal method is comparable to the normal practice used to dispose of overburden from open-pit mines. Overburden and waste rock accumulations are commonly referred to as "dumps" in the mining industry. However, these dumps usually consist of coarse gravel and larger-sized rock fragments which are not susceptible to wind and water erosion. The mining and milling industry does not usually dispose of fine wastes, such as tailings, in an open land disposal area, as suggested by this alternative.

5.5.2 Technical and Legal Considerations

Technically, this method of waste disposal is feasible. It would be similar to any large earth-moving project and the equipment and manpower would be readily available. The only technical problems would result from the fineness of the majority of the waste materials. The dry tailings would be susceptible to wind and water erosion and handling of the dry or nearly dry wastes would also be difficult to accomplish without creating dust problems.

This disposal option would certainly encounter resistance from those responsible for enforcing EPA laws and regulations. This is because of problems associated with wind and water erosion. In addition it would be necessary to control any potentially harmful leachates. Thus, this disposal method would not seem to be applicable to any of the waste products generated by the processing, except possibly the granulated slag produced in the smelting process. The granulated slag would be relatively unsusceptible to wind and water erosion, but the slag may be susceptible to the formation of leachates.

5.5.3 Summary

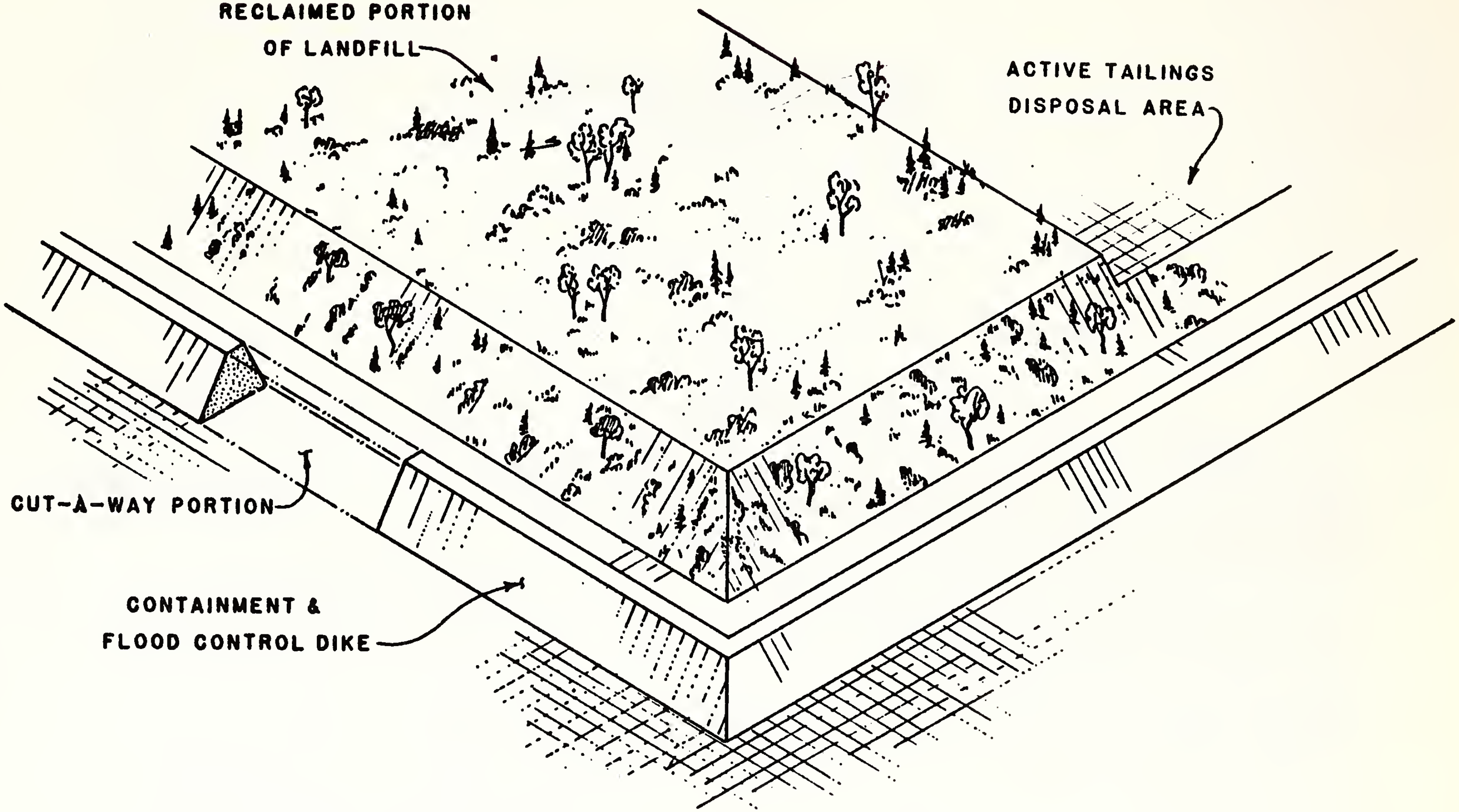
This method would probably conflict with existing and proposed environmental regulations. Therefore, it is unlikely that this method would be seriously considered for disposal of any of the waste products associated with the manganese nodule processing. The possible exception to this would be disposal of granulated slag resulting from a smelting process, if deleterious leachates would not be formed and wind and water erosion would not affect the stability of the slag piles. If slag were disposed of in this method, this site should be located in an arid or semi-arid region. The lack of rainfall would inhibit the formation of leachate, and the possibility of contamination of surface or ground water would be minimized.

5.6 ALTERNATIVE B, DISPOSAL OF WASTE IN LANDFILL

5.6.1 Description of Method

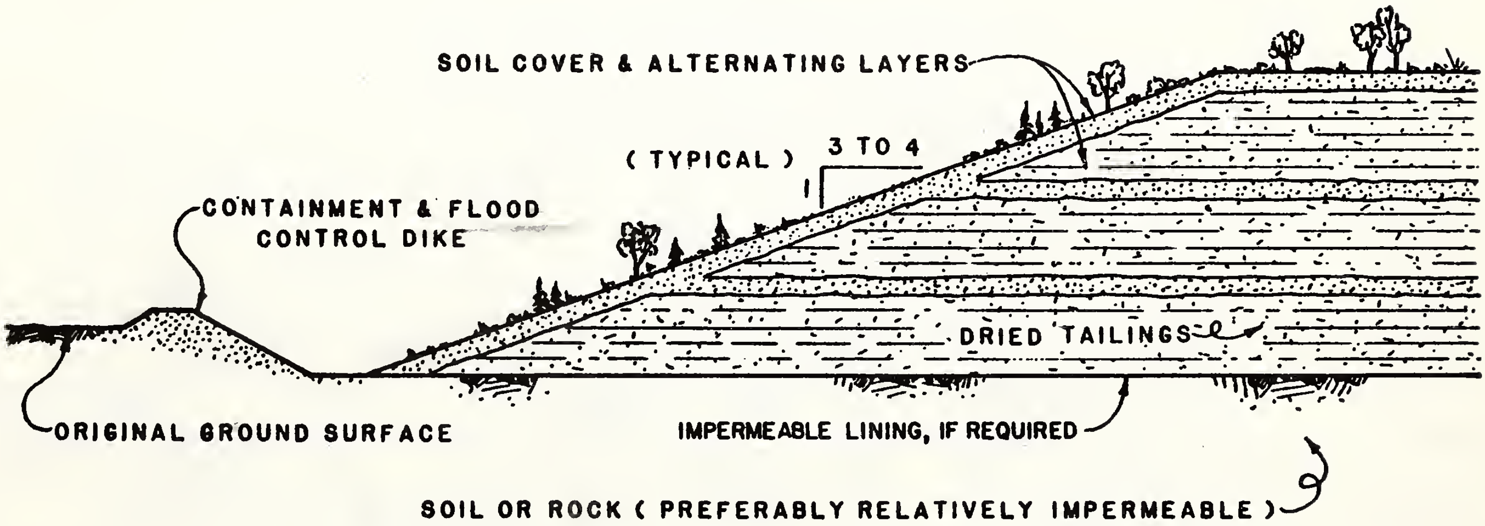
This disposal method is very similar to the first disposal method, except that the dry or nearly dry waste materials will be placed in layers with alternating layers of cover material consisting of natural, on-site soils. After construction of a given section of the landfill, the entire section would be covered with topsoil and revegetated. To protect the disposal area from flood waters and to prevent surface runoff from escaping from the disposal area, a containment and flood-control dike probably would be constructed around the disposal facility. Conventional construction equipment, consisting of scrapers, trucks, dozers, and motor graders, could be utilized for this method and no new technology would be required.

This method is similar to the practice of land reclamation which is common to the strip mining industry. In that industry, the undesirable overburden soils and rocks are placed in a landfill, usually to backfill a mined out area. Topsoil is placed over the landfill and the area is revegetated. In this case, intermediate layers of natural soil would be placed between layers of dried tailings to provide containment of the waste materials prior to completion of a given area, and to reduce formation of migration of leachates. An artist's conception of possible landfill disposal scheme is shown on Figure 5.1, Isometric View, Landfill Disposal Scheme. A section through a typical landfill disposal system is shown system is shown on Figure 5.2.



ISOMETRIC VIEW
LANDFILL DISPOSAL SCHEME

Figure 5.1


SOIL COVER & ALTERNATING LAYERS
(TYPICAL)
3 TO 4
1
CONTAINMENT & FLOOD CONTROL DIKE
DRIED TAILINGS
ORIGINAL GROUND SURFACE
IMPERMEABLE LINING, IF REQUIRED
SOIL OR ROCK (PREFERABLY RELATIVELY IMPERMEABLE)

SCHEMATIC
LANDFILL DISPOSAL SYSTEM

Figure 5.2

5.6.2 Technical and Legal Considerations

In contrast to Alternative A where the dry or nearly dry tailings would be dumped over a land disposal area, with little regard given to leachate, dust and erosion control, the disposal of process wastes in a well-designed landfill would be more advantageous for several reasons. These reasons include:

a) positive dust control resulting from the intermediate layers of cover;

b) positive leachate control, also resulting from the intermediate layers of soil cover which could be designed to retard or preclude movement of leachate into the environment;

c) ease of reclamation, because revegetation can be accomplished periodically throughout the life of the disposal area; and

d) there will be no free water in the system since dry or nearly dry waste will be handled, so the potential for leachate formation, especially once the final soil cover and vegetation is established, would be minimal.

One significant problem that may be associated with this method would be obtaining enough topsoil to cover the disposal area for revegetation purposes. Ideally, the topsoil could be obtained from beneath the disposal pile. If not, topsoil would have to be imported from a borrow area.

In view of the existing and proposed laws and regulations regarding solid waste disposal, the landfill method, with alternating layers of soil cover, would appear to be acceptable, and in many ways desirable, over alternative waste disposal methods. The method would employ the best available technology to keep hazardous materials out of the environment, including lining the landfill site if necessary. It also disposes of the waste in a form readily recoverable for secondary processing and extraction of metal values. The system can be designed to comply with all MESA guidelines regarding hydrology and safety considerations.

5.6.3 Economic Considerations

Although this method is technically and legally feasible, the cost of drying the process wastes could be substantial for all processes except the smelting process. For the 3-metal plants, as much as 510,000 tonnes (560,000 tons) per year of coal would be required to dry the tailings. This energy consumption would have to be traded off against reduced disposal area requirements, potential uses of the land after disposal is complete, and non-quantitative factors such as aesthetics. Once the wastes were dried, the costs for transportation and disposal would be similar to the costs of slurry disposal behind a tailings dam.

5.6.4 Summary

By definition, the method is only applicable to dry or nearly dry solid waste materials. Therefore, any liquid wastes which are produced by the process, or which result from washing of the solid waste materials, would have to be disposed of in an alternative system, such as a lined evaporation pond or a conventional slurry tailings system (as described in a later section).

Since the formation of deleterious leachate would likely be the most significant problem associated with a landfill disposal method, it would be desirable to locate the landfill in an arid or semi-arid region. Also, the landfill should preferably be located in an area where the subsurface geology consists of relatively impermeable soil and/or rock. If such a site could not be located, it might be necessary to import clays to provide a compacted, relatively impervious base for the landfill, or to place an artificial plastic or rubber-membrane-type lining beneath the landfill to prevent possible contamination of ground water.

The selection of the components of this system and the need for a positive seal at the bottom of the landfill would be based on the character of the waste materials, the subsurface geologic and hydrologic conditions, and the climatic conditions at the given site. The landfill method of waste disposal could be designed to accommodate any of the solid, dried wastes which would be produced from the five possible manganese nodule processes. The main drawback would be the cost of energy required to dry the tailings prior to disposal.

5.7 ALTERNATIVE C, COVER MATERIAL FOR SANITARY LANDFILL

5.7.1 Description of Method

This waste disposal alternative would use washed and dried wastes from the processes for cover material in a municipal sanitary landfill. The current practice in sanitary landfills is to systematically dispose of sanitary wastes in a given portion of the landfill. After each day's disposal, that section of the landfill is covered with 0.6 to 0.9 meters (2 to 3 feet) of soil. These isolated pods of sanitary fill surrounded by soil are termed "cells." Preferrably, the soil used to cover the cells is a silty or clayey soil relatively low in permeability, so that air and water are kept out of the cell and leachate is kept within the cell as much as possible.

5.7.2 Technical and Legal Considerations

This disposal method would probably encounter major inpediments, such as finding a municipality which would need the quantity of cover material which would be produced from a manganese nodule processing plant, or which would be willing to accept the liability for the potential pollution resulting from placing processed wastes in their fill. The most significant advantage of this method would be that the waste would be disposed of along with other wastes, and the total amount of new land disturbed would probably be less than from any other method of waste disposal.

However, there are several technical problems with this method. Unless the process wastes themselves were covered with an impermeable soil, the process wastes may be leached by leachates formed in the sanitary fill. That is, acidic leachates formed from the sanitary landfill could liberate "hazardous" elements or compounds from the neutralized process wastes. Another problem would be developing a distribution system to handle the waste materials. No single sanitary landfill would be able to cope with the volume of waste which would be produced by one of the process plants. Therefore, the waste would have to be distributed to several municipalities. The transportation, handling, safety problems, and costs associated with this would be significant. For instance, the waste from a 3-metal process plant, if placed in a compacted layer 0.9 meter (3 feet) thick, would cover more than 240 hectares (610 acres) per year, or more than 20 hectares (50 acres) per month. From a 4-metal plant, approximately 40 hectares (100 acres) per year, or 3.2 hectares (8 acres) per month, would be covered under the same conditions.

There is an important legal consideration in placing processed waste in a sanitary landfill. One of the primary goals of the Resource Conservation and Recovery Act is to ensure that waste materials are placed in a form where they can be readily reclaimed if another use for these materials is determined in the future. Scattering process wastes in sanitary landfills could be interpreted as a direct contradiction with the intent of this law. This is because anything placed in a sanitary landfill would never be recoverable from a practical point of view. Also, control of the leachate which could be formed from the action of acidic organic leachates acting on the inorganic process wastes could potentially be a very difficult problem; this would make compliance with the Safe Drinking Water Act difficult.

5.7.3 Summary

Because of the major problems associated with this disposal method, it is unlikely that this alternative would be seriously considered by industry. If it were used, it would probably require a separation of all of the metal oxides and soluble portions of the effluent streams from relatively inert clays or clay by-products resulting from the process. Only the clayey materials would seem to be amenable for use as cover material in a sanitary landfill. However, the cost of making this separation at the end of a processing plant would be significant; even if the separation were made, an alternative waste disposal system (such as a conventional slurry tailings disposal system) would still be required to handle the bulk of the waste materials.

5.8 ALTERNATIVE D, CONVENTIONAL TAILINGS SLURRY DISPOSAL SYSTEM

5.8.1 Description of Method

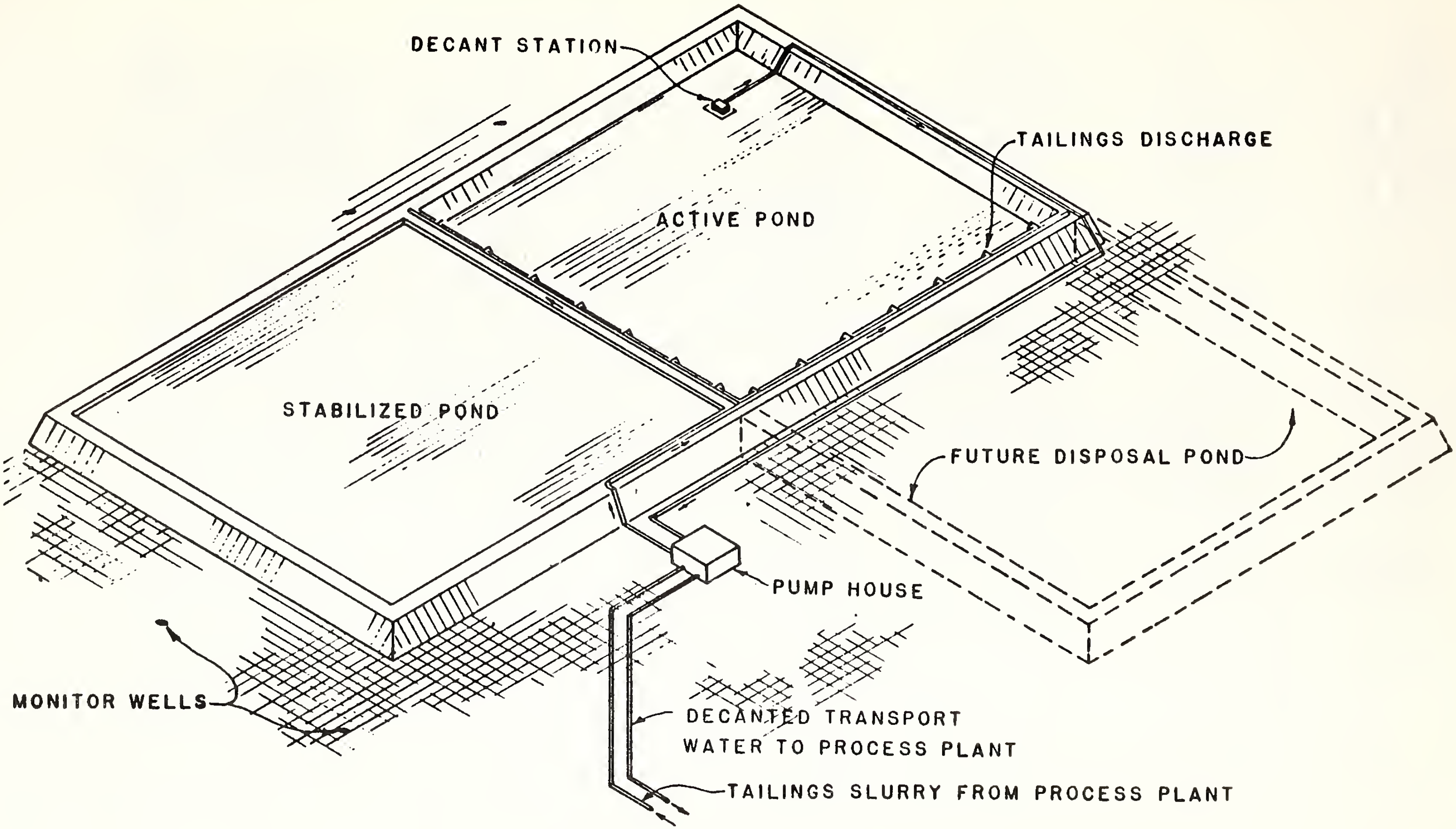
Essentially, the conventional tailings disposal method consists of an earth embankment behind which the waste materials are deposited in slurry form. The embankment can either be a total enclosure (as illustrated on Figure 5.3, Isometric View, Tailings Disposal Scheme), or it can be a cross valley or side-hill type (Swaisgood and Toland, 1973). The tailings are transported to the disposal area in a slurry pipeline and are deposited into the reservoir behind the embankment through a series of distribution pipes and spigots. The design of the tailings embankment has to be such that it is stable under static and dynamic loading conditions, is capable of handling design floods (MESA, 1976), and so that seepage is controlled through the embankment (Toland and Versaw, 1976).

This technique is the most commonly used method to dispose of fine waste resulting from the processing of ore. However, granulated slag produced in the smelting process or fused salt blocks could also be deposited behind a tailings dam. The technology required to utilize this method in compliance with environmental and safety laws and regulations readily available to the mineral industry.

5.8.2 Technical and Legal Considerations

There are several advantages of utilizing a conventional tailings disposal system for disposing of the process waste. Given the availability of synthetic liners and/or favorable geologic conditions and proper construction of an earthen embankment, the tailings reservoir can be made into a closed system. Thereby, negligible amounts of solid or liquid wastes are allowed to escape into the environment. Another advantage of this type of system is that no treatment of the process waste is required before disposal. In all of the previously described methods, the process wastes have to be at least dried, which requires a substantial use of energy. Another significant advantage of this technique is that all of the process wastes can be placed in one location. No separation of ash or soluble solids, or removal of toxic trace elements is required prior to disposal. Finally, since this method is the conventional practice and the technology has already been developed to assure its compliance with environmental rules and regulations, there is virtual certainty that no unforeseen problems would develop in the future.

There are some disadvantages, however, to the conventional tailings disposal system. These include a problem of controlling dust, particularly after disposal has ended in a given area, and the related problem of reclaiming the disposal area. In particular, some of the process waste may always retain a relatively high moisture content and they may never be stable enough to support construction equipment. Therefore, the conventional reclamation process of spreading topsoil over the disposal facility and revegetating would be difficult. Another disadvantage of this type of system is that substantially more land area is consumed than with a dry landfill-type disposal system. This is because the slurried waste materials have a much lower in-place density than the same materials have when dry. With a 12.2 meter (40-foot) thick layer



ISOMETRIC VIEW
TAILINGS DISPOSAL SCHEME

Figure 5.3

of tailings approximately 40 hectares (100 acres) of land would be required each year to dispose of the wastes from a 3-metal plant. At the same thickness, approximately 8 hectares (20 acres) would be required each year to dispose of the wastes from a 4-metal plant. These areas are double the estimated land requirements for disposal of the same amount of dried wastes.

5.8.3 Economic Considerations

The lowest disposal cost of any land method would be for this system. This is because the wastes are handled in the form they are produced and because slurries can be transported relatively inexpensively as described in Chapter 4.0.

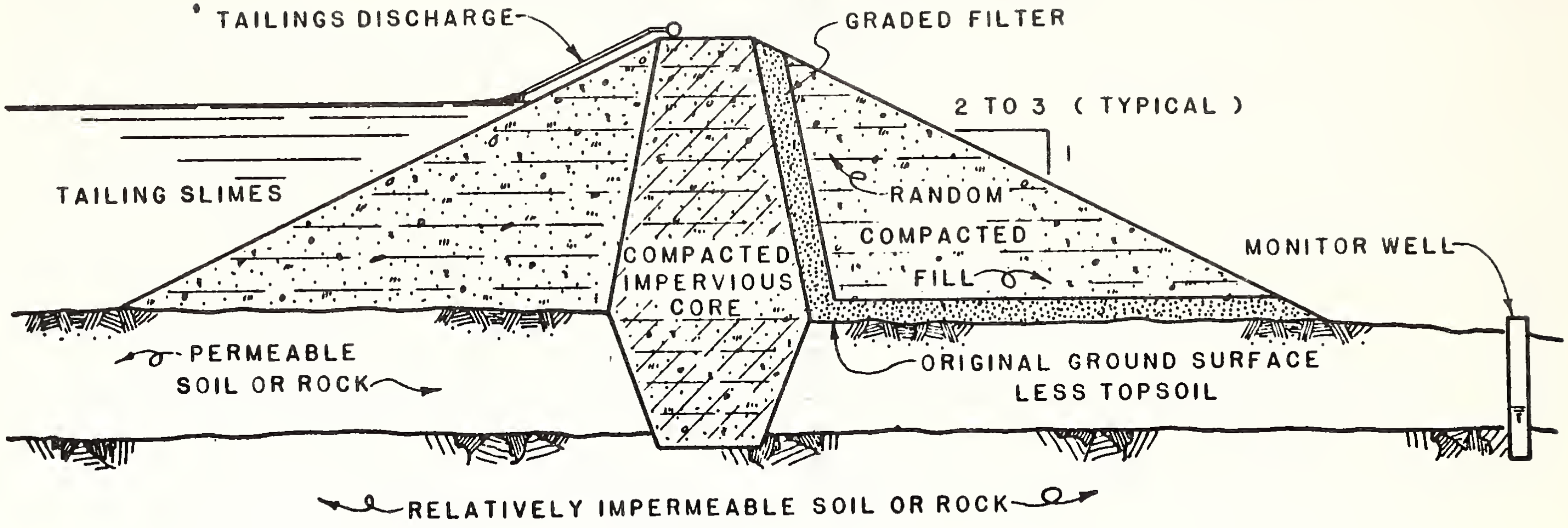
5.8.4 Summary

The tailings disposal system can be used for all of the types of waste which would be produced by any of the five process routes. However, the common practice of utilizing the coarse fraction of the tailings for construction of a portion of an embankment would not be feasible for any of the manganese nodule process wastes except possibly the granulated slag from the smelting process (Klohn and Maartman, 1973).

Another common practice in the mineral industry is to utilize stage construction to gradually increase the height of the embankment over the life of the project (Swaisgood and Toland, 1973). This procedure could be used, but, for stability and seepage-control reasons, only the downstream method of embankment construction would probably be applicable.

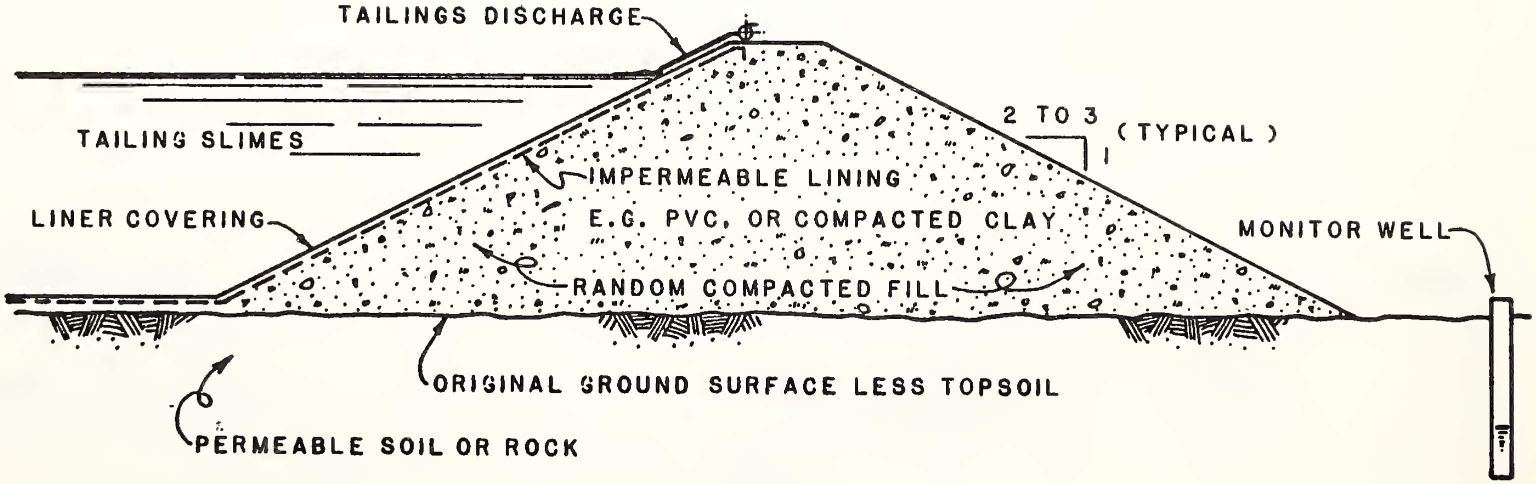
Obviously, a major consideration of a tailings disposal system is the seepage characteristics of the foundation materials upon which the embankment and reservoir would be situated. If a site can be chosen where the subsurface soils consist of essentially impervious soil or rock and where borrow materials can be obtained to construct the conventional zoned embankment, then a tailings embankment as shown on Figure 5.4, Schematic Typical Tailings Embankment (Unlined) can be constructed. On the other hand, if the subsurface soils are relatively permeable, then the embankment face and reservoir area would probably have to be lined either with imported clayey soil or with man-made plastic or rubber membranes. This type of system is shown on Figure 5.5, Schematic, Typical Tailings Embankment (Lined).

Normally, it would be preferable to locate the tailings disposal facility in an arid or semi-arid region where the climatic conditions result in a large net evaporation. Given this condition, the reservoir area can be sized according to the area needed to evaporate excess slurry transport water. However, if the tailings disposal structure is located in an area where the net evaporation rate is low it may be necessary to install a decant system to collect excess water from the tailings disposal area and to recycle it to the process plant. A decant system is often installed even when a tailings disposal facility is



SCHEMATIC
TYPICAL TAILINGS EMBANKMENT
(UNLINED)

Figure 5.4



SCHEMATIC
TYPICAL TAILINGS EMBANKMENT
(LINED)

Figure 5.5

located in an arid or semi-arid region to enable the recycling of the transport water. This lowers the requirement for make-up water. The need for a decant system and the volume of water to be handled have to be determined on a site- and plant-specific basis.

5.9 ALTERNATIVE E, STORAGE OF MANGANESE ORE FOR FUTURE PROCESSING

5.9.1 Description of Method

Essentially, this method involves stockpiling of manganese ore - not waste disposal. In a 3-metal plant, the manganese portion of the nodules normally would go to the waste disposal area as part of the tailings. If this method were implemented, the manganese oxide would be recovered in the process plant and stockpiled for future extraction of manganese metal. As much as 2300 mtpd (2500 tpd) of manganese could be stored if this method were implemented. Because of the fine silt-sized character of the manganese oxide, the manganese would have to be stored in closed silos or bins, or at least covered to prevent wind and water erosion.

5.9.2 Technical and Legal Considerations

As long as the manganese ore was stored in a closed container such as a silo or bin, or adequately covered and protected from wind and water erosion, there should not be any problems complying with federal regulations. Also, the technology to do this is readily available.

5.9.3 Economic Considerations

From a technological and legal viewpoint, manganese ore could be stored at a plant site. However, there are economic considerations which would probably preclude this option from ever being seriously considered by industry. In Chapter 2.0 of Volume I, it has been indicated that the principal reason why manganese would not be recovered from many of the manganese nodule operations is because the market for manganese is small. The manganese production from a single 4-metal plant would represent 30 percent of the total consumption of the United States. This fact was a major factor in sizing of 4-metal plants at approximately 1.1 million mtpy (1.25 million tpy) versus 3-metal plants at 3.7 million mtpy (4.1 million tpy).

The manganese which is sent to disposal areas each day from a single 3-metal plant would be approximately equivalent to the total daily U.S. consumption. Therefore, it is unlikely that anyone would consider stockpiling manganese. If the need for additional manganese ever occurred, the tailings or landfill could be reclaimed and reprocessed to extract the manganese ore. In effect, the landfill and conventional tailings disposal systems would be manganese ore stockpiles which could be exploited if the need were present. The principal limiting factor in obtaining the manganese would not be the availability of the ore, but the availability of the processing equipment.

5.10 ALTERNATIVE F, OCEAN DUMPING

5.10.1 Description of Method

This method would consist of transporting the nodule process wastes from the plant to a port facility and into the hold of dumping barges or outbound nodule transport vessels. It has been assumed that the wastes are either suitable for obtaining a dumping permit or have been suitably treated in order to obtain a permit.

Conventional dumping barges are simply loaded through the weather deck hatches and dewatered to the sea by overflowing. At the disposal site, barges open a hatch in the bottom and the wastes slide out - a simple and inexpensive procedure. Because of the enormous volumes to be handled, even under the smallest load, about two barge loads per week of solids would be dumped. This would be about a single 6000 DWT barge towed not far beyond the 320 kilometers (200-mile) limit, weather permitting. Alternatively, a pair of 8000 DWT barges and tugs could dump over 920 kilometers (500 nautical miles) at sea, at a much higher cost. These barges and their tugboats are substantial vessels and investments, but they are proven and economical equipment.

The principal disadvantage of dump barges is that the surface disposal of the tailings may leave a near-surface plume of sediment, which would spread as it falls through the ocean to the bottom. Also with the barging system, little other use of the dump barges is possible and when when the slurry is loaded into the dump barge, overflow of slurry liquids may occur.

Another feasible mode of waste tailings disposal would be to pump the slurry aboard ship, dewater, transport to the deep sea, and pump slurry overboard using the shipboard equipment. This dumping method is more expensive than bottom dropping, because of the pumping requirements. One advantage of the slurry ship is the possibility to dump the waste through a pipe suspended from the ship to a deeper water level, perhaps several hundred feet below the surface. This would place the plume below the surface water and sunlight penetration zone, where any potential harmful effects would be mitigated because of the lessened biological life. Since a separate fleet of dumping barges would not be required if the transport vessels were also used to dispose of the tailings, the transport vessels would most likely be used to dump the tailings at sea if ocean disposal was selected. This method is illustrated on Figure 5.6.

5.10.2 Technical and Legal Considerations

The obvious advantages of ocean dumping are that no land would be required for waste disposal and the potential for spills, leachate seepage, and dusting would be virtually eliminated.

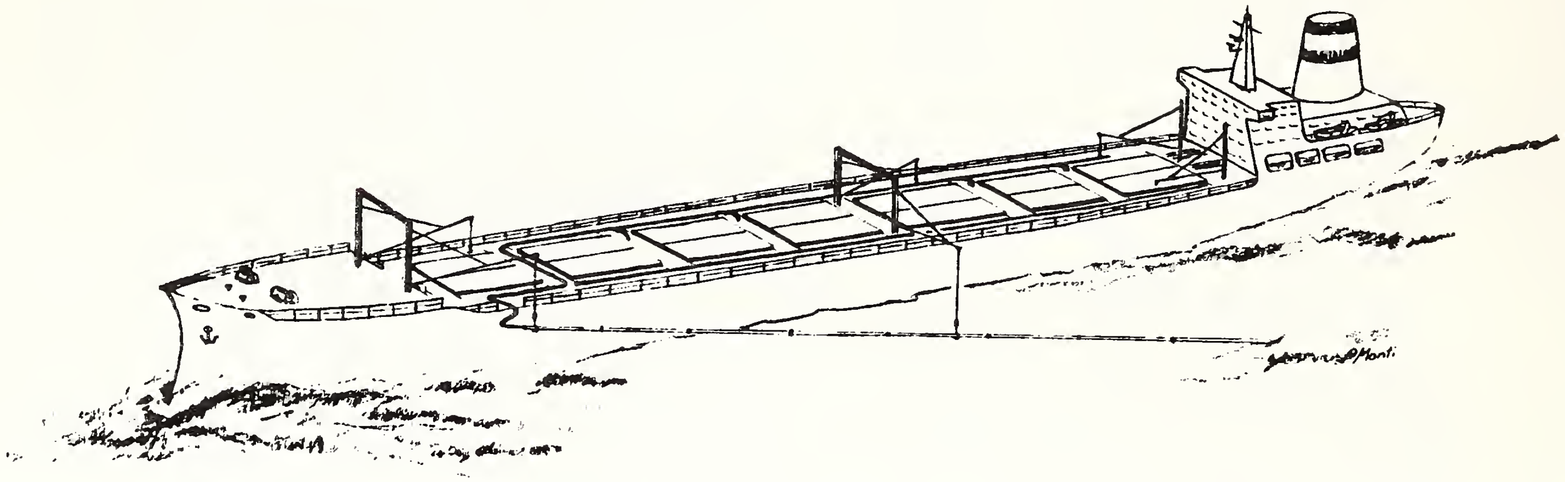


Figure 5.6: Disposal of Slurry Wastes At Sea

The technology for ocean dumping is available. Present systems would have to be adapted to handle the particular types and quantities of wastes that will be produced. The main questions relating to this method are legal, not technical. At this writing, it is not possible to say whether ocean dumping would be allowed or not.

5.10.3 Economic Considerations

If ocean dumping of process wastes is allowed, it would be much less expensive than any type of land disposal. However, if special treatment of the wastes, such as removal of toxic elements, is required prior to dumping, then the economic advantage may be less. This method would require less capital investment than land disposal techniques since essentially most of the equipment required to handle the slurry would already be available. That is, the tailings could be transported to the port in the same slurry lines used to transport the incoming nodules to the plant and the same transport vessel could be used to dispose of the tailings as is used to bring the nodules to port.

5.10.4 Summary

Although the legal situation is uncertain, the significant advantages of ocean dumping over any other method certainly would insure that the nodule mining industry would seriously consider this as a desirable waste disposal method.

5.11 CONCLUSION

The outstanding environmental, legal, and technical considerations for six alternative waste disposal systems have been considered in the previous paragraphs in this section of the report. These systems include land disposal, disposal in a landfill, disposal by using the waste as a cover material for sanitary landfill, conventional slurry tailings disposal system, storage of manganese ore at the plant site, and deep-ocean dumping. Based on the reasons described in the previous sections for each of these types of disposal, it is our opinion that three of these systems may be seriously considered by industry as potential waste disposal alternatives, and three of the disposal systems would not be seriously considered by industry as potential waste disposal alternatives.

The alternatives which may be seriously considered by industry for the first-generation processing plant waste disposal are: disposal in a landfill; disposal in a conventional slurry tailings disposal system; and disposal by deep-ocean dumping. In Section 6.0, Detailed Description of Probable Disposal Systems, each of these three systems are described in detail. These descriptions include the structural and mechanical requirements for each system and the support requirements for each system, including land, manpower, fuel and power consumption, water consumption, and reclamation.

6.0 DESCRIPTION OF MOST PROBABLE DISPOSAL ALTERNATIVES

6.1 INTRODUCTION

In Section 5.11 it was concluded that three waste disposal systems would be seriously considered by the nodule processing industry. These include:

1) disposal in a landfill;

2) disposal in a conventional slurry tailings disposal system; and

3) disposal by deep ocean dumping.

This section of the report describes these systems in detail. Specifically these descriptions will include the structural and mechanical requirements for each system and the support requirements for each system including land manpower, fuel and power consumption, water consumption and reclamation.

6.2 BURIAL OF PROCESS WASTE IN LANDFILL

Essentially, this method consists of placing dry or nearly dry process waste in a landfill with alternating layers of soil and a topsoil cover on the top and sides of the landfill for re-establishing vegetation. Conceptually, this type of system is illustrated on Figures 5.1 and 5.2. If the soil or rock underlying the landfill are not relatively impermeable, then it may be necessary to seal the site with an impermeable lining. Some provision, such as a dike around the landfill would be required for flood control and containment purposes.

6.2.1 Characteristics of Suitable Sites

Because of legal requirements which prohibit contamination surface and groundwater and require that dusting and erosion from the landfill does not occur, it is preferable that a disposal site have certain characteristics. These include:

1) location away from a floodplain and surface drainage

2) relatively "impermeable" subsoil or bedrock

3) on-site availability of borrow materials including topsoil

4) low groundwater table

5) large enough area to put all wastes in one fill rather than creating multiple fills

Ideal sites are seldom found. Engineering judgments have to be made to decide if a given site with particular deficiencies, such as permeable subsoil, could be upgraded to comply with regulations. Procedures, such as importing a clay lining, can be implemented, but their cost may make a given site uneconomical.

6.2.2 Site Preparation

Prior to utilizing a site, considerable site preparation will have to be completed. The topsoil and vegetation should be stripped and stockpiled for future use as cover material. Additional soil should also be stripped and stockpiled to provide for the intermediate layers in the landfill. Large trees and the like may have to be disposed of in a sanitary landfill or buried in the landfill.

Normally only a portion of the landfill would be prepared at any one time. One year or less of land area would be a likely amount to be stripped so that disturbance to surrounding land is minimized.

The bottom of the landfill would probably require some leveling. This is particularly true if a lining will be required to control leachate seepage. Compacted clay or membranes such as PVC could be used to control seepage.

Other types of site preparation would include constructing a flood protection dike, if necessary, constructing unloading facilities for conveyors, building access roads, erecting structures such as shop and office buildings and the like.

6.2.3 Transportation Requirements

As noted previously, the landfill waste disposal system assumes that the waste will be a dry or nearly dry, fine grained, soil-like material. Thus the transport of the waste would be very similar to the transport of the raw nodule or dry ground ore which was discussed in Chapter 4.0. Therefore, the possible dry waste transportation modes could consist of any one of the following: rail haulage; truck haulage or conveyor.

Since the location of the landfill disposal site is unknown, it is virtually impossible to select one most likely mode. This is due to the fact that three very logical scenarios can be developed such that a different transport mode would be most likely for each scenario. The three scenarios and the most likely transport mode associated with each are described below. It should be kept in mind, however, that industry would make every effort to locate the waste disposal site relatively close to the plant site.

6.2.3.1 Disposal Site Within 8 kilometers of Plant

For a disposal site located within 8 kilometers (5 miles) of the plant, the possible transport modes reduce to truck haulage and conveyor.

For the purpose of comparing these, it was assumed that the disposal site would be located such that it would not be necessary to use public roads for the truck haul.

Truck haulage was assumed to utilize large, off-highway type units. Tractor-trailer units of the 90 tonnes (100-ton) bottom dump variety were assumed. For an 8 kilometer (5 mile) haul distance, nine such units working one shift per day would be required for a 3-metal plant while 3 units would be required for a 4-metal plant. The hauling units would be provided with removable covers to control dust loss during travel.

A covered belt conveyor system consisting of a 76 cm (30-inch) wide belt for a 3-metal plant or a 61 cm (24-inch) wide belt for a 4-metal plant would be required. The system would be electric motor driven and capable of transporting the wastes at the required rate of 460 mtph (505 tph) for the 3-metal plant and 75 mtph (82 tph) for the 4-metal plant. A 24-hour per day operation was assumed when sizing the system.

Based on the data developed for hauling dry ore, the truck haul system has a first cost advantage for the tonnes (tonnages) associated with a 4-metal plant but the situation reverses for the higher tonnes produced by a 3-metal plant. Operating costs favor the conveyor system for both plant sizes. Environmental and safety considerations also tend to favor the conveyor system. Thus, it is concluded that a conveyor system would likely be utilized to transport wastes from the mill to the disposal site if the landfill site is located within 8 kilometers (5 miles) of the plant. The equipment and resource requirements for the conveyor system are presented in Table 6.1.

6.2.3.2 Disposal Site More Than 8 kilometers From Plant And Not Along Rail Line

This scenario assumes the disposal site to be greater than 8 kilometers (5 miles) from the plant but located such that existing rail lines cannot be utilized. For this case, the distance becomes too great for the conveyor haulage and the high cost of new rail lines would eliminate rail haulage from consideration. Thus the most likely mode of transport would be truck haul. For the distances considered, it was assumed that use of public roads would be necessary thereby limiting truck size to 18 tonnes (20-ton) units. These units would be similar to those discussed for ore haulage in Chapter 4.0. The equipment requirements for the truck haul system are presented in Tables 6.2 and 6.3.

TABLE 6.1

LANDFILL WASTE TRANSPORT EQUIPMENT AND RESOURCE REQUIREMENTS

Item	3-Metal Plant (Productions Rate 460 mtph or 505 tph)	4-Metal Plant (Production Rate 75 mtph or 82 tph)
Conveyor System Size (Belt Width)	76 cm (30 in.)	61 cm (24 in.)
Vibrating Feeder System and Motor Horsepower (HP) Requirement	1.2 meter (4-foot) minimum width feeder; 18.7 kw (25 HP) motor	0.9 meter (3-foot) minimum width feeder; 15 kw (20 HP) motor
Energy, electricity (kilowatts)		
for 31 m (100 ft)	37	34
for 305 m (1000 ft)	75	71
for 3050 m (10,000 ft)	535	540
for 8 km (5 miles)	1400	1400
Shift Labor Personnel Required		
for 31 m (100 ft)	one operator	one operator
for 305 m (1000 ft)	one operator plus one laborer	one operator plus one laborer
for 3050 m (10,000 ft)	one operator plus two laborers	one operator plus two laborers
for 8 km (5 miles)	one operator plus one mobile 3-man crew (laborers)	one operator plus one mobile 3-man crew (laborers)
Land Requirement	6 hectares per km (9 acres per mile)	6 hectares per km (9 acres per mile)

TABLE 6.2

TRUCK TRANSPORT OPERATION AND EQUIPMENT REQUIREMENTS
FOR DRY WASTE. 3-METAL PLANT

Distance Plant-to-Port in Kilometers (Miles)		Number of Shifts Assumed	Number of Trucks Required
8	(5)	1	38
80	(50)	3	68
161	(100)	3	122

TABLE 6.3

TRUCK TRANSPORT OPERATIONS AND EQUIPMENT REQUIREMENTS
FOR DRY WASTE. 4-METAL PLANT

Distance Plant-to-Port in Kilometers (Miles)		Number of Shifts Assumed	Number of Trucks Required
8	(5)	1	7
80	(50)	2	17
161	(100)	2	33

6.2.3.3 Disposal Site More Than 8 Kilometers From Plant Located Along Existing Rail Line

For this scenario, the possible modes of transport are again truck and rail. However, since the site is located adjacent to an existing rail line, rail transport would be preferable over truck transport. The reasons for this conclusion were discussed in detail in Chapter 4.0. Generally, rail transport is much safer and less expensive than truck transport if existing lines can be used. Thus, the most likely transport system for this scenario would be rail transport.

The equipment requirements of the rail system are presented in Tables 6.4 and 6.5.

TABLE 6.4

RAIL TRANSPORT EQUIPMENT REQUIRED FOR DRY WASTE. 3-METAL PLANT

Distance Plant-to-Port in Kilometers	(Miles)	Locomotives Per Unit Train	Rail Cars Per Unit Train	Number of Trains Required
8	(5)	1	18	1
80	(50)	3	61	2
161	(100)	3	61	2

TABLE 6.5

RAIL TRANSPORT EQUIPMENT REQUIRED FOR DRY WASTE. 4-METAL PLANT

Distance Plant-to-Port in Kilometers	(Miles)	Locomotives Per Unit Train	Rail Cars Per Unit Train	Number of Trains Required
8	(5)	1	3	1
80	(50)	2	20	1
161	(100)	2	20	1

6.2.4 Method of Operation of Landfill

The landfill would probably be built up by a series of lifts of approximately 3 meters (10 feet) in thickness. Each lift would cover a small portion of the total landfill area and then be covered with natural soil to reduce dust and erosion. The final lift, assumed to be after a fill height of approximately 12.2 meters (40 feet) is achieved, would be covered with topsoil and revegetated according to local requirements.

If the wastes are brought to the site by conveyor or train, they would be transferred into scrapers for spreading into lifts. The transfer equipment might consist of large bins or silos which would receive wastes from the conveyors or rail cars via conveyor. The scrapers would be loaded by gravity means, directly from the silos. This procedure would be similar to the method used to load coal into unit trains.

If the wastes are trucked to the site, then, most likely, those trucks will be used to dump the wastes on the landfill. No special equipment would be necessary to compact the wastes, since the truck or scraper traffic should handle this adequately. However, grader and dozer equipment would be necessary to smooth and distribute wastes dumped on the fill. Also, a water wagon would be required to keep the fill surface moist which will reduce dust problems.

The equipment listed in Table 6.6 would be required to operate landfills for 3-metal and 4-metal plants. It is assumed that the fills would be operated on a 24 hour per day basis to maximize equipment use.

TABLE 6.6

LANDFILL EQUIPMENT REQUIREMENTS

Item	Number Required (3-Metal Plant)	Number Required (4-Metal Plant)
Tractor/scraper (Cat 631D)*	5	2
Motor grader (Cat 140G)*	1	1
Crawler/dozer (Cat D8K)*	1	1
Water wagon (modified 631D)*	1	1
Pickup truck (3/4 ton)	2	2
Light plant (4 kilowatt)	4	2
Fuel storage and pumps	52 m^3 (14,000 gal)	23 m^3 (6000 gal)
Bin storage	14,000 m^3 (18,000 cu yds)	2300 m^3 (3000 cu yds)

*Describes type and size of equipment and does not represent an endorsement of a specific manufacturer's product.

Other specialized equipment, such as for fertilizing and seeding, will be required. However, these types of equipment would only be used for a few weeks out of each year and presumably would be rented or contracted on the outside. Their significance, in terms of capital requirements or fuel consumption, are negligible compared to the rest of the project needs.

6.2.5 Reclamation

Reclamation of the disposal area to an environmentally and aesthetically acceptable condition will be required. For this type of landfill where the materials are dry solids, reclamation is relatively easy and effective if it is included as part of the overall project planning. Reclamation should consist of placing about 0.6 meters (2 feet) of topsoil over completed portions of the landfill. The slopes of the landfill should be maintained at an inclination of about 3 horizontal to 1 vertical or flatter to facilitate movement of equipment and to retard erosion of the slopes during the period of time while the vegetation is becoming established. Nutrients such as organic material and fertilizer may have to be added to the topsoil before seeding. The types of vegetation to be planted would depend on the geographic location of the landfill. If the landfill is located in an arid or semi-arid region, the seeded areas may need to be irrigated until the cover crops are sufficiently established. Maintenance, including reseeding of areas that may not grow well at first, may be required.

One of the principal advantages of disposal of the process waste in a landfill is that the area can be relatively easily reclaimed, and that the reclamation can be accomplished as soon as a portion of the landfill is completed. Another advantage is that alternate uses of the landfill can be identified since the final product is structurally sound. These include light industrial sites, grazing, and the like.

6.2.6 System Resource Requirements

In this section, the land, manpower, energy, and water requirements for the landfill method of waste disposal are identified for typical 3-metal and 4-metal disposal facilities. (Note: The resource requirements for the transportation system were specified in Section 6.2.3.) The land requirements are based on the assumption that the dry or nearly dry waste materials would have an in-place density of 100 pounds per cubic foot in the landfill, and that the landfill will be comprised of a 40-foot thickness of waste materials, not including the thickness of the alternating soil layers and soil cover.

The manpower requirements are based on the manpower needed to operate and maintain the landfill equipment and including supervisory maintenance personnel.

The energy requirements are specified in terms of cubic meters/ gallons of gasoline and diesel fuel consumed by the equipment and the number of kilowatts which will be utilized by electrically-operated equipment.

The water consumption for the landfill method is low since the system is essentially dry. However, a certain amount of water would be required to prevent dust problems caused by the drying out of the landfill surface in areas where cover material has not been applied. Some water might also be required for irrigation of newly planted vegetation. The estimated land, manpower, energy, and water requirements for the landfill disposal method are summarized in Table 6.7.

TABLE 6.7

LANDFILL SUPPORT REQUIREMENTS

Item	3-Metal Process Waste	4-Metal Process Waste
Land, hectares/yr (acres/yr)	20 (50)	4 (10)
Manpower, man-shifts/day	20	5
Gasoline, m^3/yr (gallons/yr)	87 (23,000)	27 (7,000)
Diesel, m^3/yr (gallons/yr)	1,640 (432,000)	270 (71,000)
Electricity, kilowatts	230	120
Water, million m^3/yr (million gallons/yr)	0.087 (23)	0.023 (6)
Cover material (topsoil), m^3/yr (yd^3/yr)	62,000 (90,000)	12,000 (15,000)

6.3 SLURRY TAILINGS DISPOSAL SYSTEM

The use of a tailings disposal system is the most common method in the mineral industry today for disposing of solid or liquid process wastes. Essentially, a tailings disposal system consists of an earth embankment; a reservoir behind the embankment; a distribution system to discharge the tailings into the reservoir; and in some cases, a decant system to collect and return decanted slurry transport water. An artist's conception of a tailings disposal system, which would be constructed on relatively flat ground, is shown on Figure 5.3. It is estimated that if the tailings are placed 12.2 meters (40 feet) deep, then approximately 40 hectares (100 acres) and 8 hectares (20 acres) per year of land would be required for 3-metal and 4-metal plants, respectively.

6.3.1 Characteristics of Suitable Sites

Legal restraints require that tailings slurries be disposed of in a manner that would preclude contamination of the environment from either seepage or particulates. Therefore locating a suitable site is essential or else substantial costs may be incurred to "seal" a site. The same criteria as mentioned in Section 6.2.1 apply to tailings dam sites also. However, because of the nature of tailings slurry, seepage control and embankment stability become very significant site selection factors. For instance, having to place a compacted clay lining or membrane type lining at a site can easily double the disposal costs. Stability concerns dictate, if possible, locating dams away from active seismic areas and providing for internal seepage control in the embankment. The latter could require large volumes of both clay and sand and gravel borrow materials which are not readily available at many sites. (See Figure 5.4).

6.3.2 Site Preparation & Dam Construction

Prior to disposing of wastes, several site preparation steps would be required. First of all, the topsoil should be stripped and stockpiled for later use in revegetation. Depending on the permeability of the on-site soil and bedrock either a lined (Figure 5.5) or unlined (Figure 5.4) embankment would be constructed. If the site is underlain by relatively impermeable soil or rock and granular and clayey borrow materials are available, then an unlined embankment would probably be constructed. If, on the other hand, the soil or rock at the site is relatively permeable, a lined embankment and reservoir would probably be required. In either case, monitor wells around the perimeter of the structure would be required to monitor the ground water quality in the vicinity of the disposal area, and to act as a warning system in the event that leakage from the disposal facility was of a quantity and character to deteriorate the local ground water quality. If significant seepage occurs, then a system of wells or interceptor ditches would then have to be installed to intercept the seepage and pump it back into the tailings disposal facility. If, however, the structure is properly constructed the latter should not be required and the monitor wells would show little or no deterioration in water quality throughout the life of the structure.

The volume of materials which would be required to construct a tailings embankment would vary depending on the topography at the site, the type of embankment constructed and the volume of wastes to be stored. Typically the volume of earth in the embankment would range from 5 to 10 percent of the volume of wastes contained. Therefore total embankment volumes of 7.6 million cubic meters (10 million cubic yards) or more could be required to contain 25 years of wastes from a 3-metal plant. Correspondingly smaller embankment volumes would be required for the wastes from a 4-metal plant. Whenever possible, the embankment would be constructed from borrow materials taken from within the disposal area to minimize disturbance of land outside the disposal area. The same types of equipment outlined for the landfill disposal method would be used to construct the tailings embankment. The difference would be that this equipment would be used only periodically, instead of continually.

Probably the tailings embankments would be built in stages. This would be accomplished either by periodically adding new "compartments" for slurry disposal pond (as illustrated in Figure 5.3) or by periodically adding to the height of the initial embankment. The latter would more likely be the method used to increase the height of cross-valley dams which normally are not initially constructed to their maximum because of the enormous front end capital cost.

6.3.3 Transportation Requirements

Depending on topography and distance from the plant to the disposal site, the slurry tailings could be transported by a gravity flow pipe system or by a pressurized slurry pipeline. Both of these possibilities are described in the following sections.

6.3.3.1 Disposal Site Less Than 8 Kilometers From Plant Site

When siting new ore processing projects, an attempt is made to locate the facilities to allow gravity flow of the slurry tailings from the plant to the disposal pond. For this scenario with the disposal site near the plant, it was assumed that site conditions for this project would be such that a gravity flow system could be installed.

With a gravity flow tailings transport system, the tailings are sluiced with water from a holding pond at the mill, into a conveyance pipe. The pipe would probably be a concrete or plastic compound pipe which is laid on the ground surface. The grade of the pipe is such that open channel flow at a velocity above the scouring velocity is maintained. If the topography is suitable, the pipeline can be routed to the crest of the empoundment dam to discharge directly into the tailings retention pond.

For the purpose of this report, adverse topographic conditions have been assumed which consider flat terrain with a perimeter dike enclosing the disposal pond. This dike arrangement requires that the gravity flow pipeline discharge into a receiving tank or to a pump station sump where it is then pumped over the dike and into the holding pond.

The resource requirements for this system would consist of the pipe required to transport the tailings and one man, on a part-time basis, to patrol and inspect the pipeline and to inspect the sluicing facilities. This man would be a part of the manpower requirements for operation and maintenance of the dam and dam pumping station. The man has been included in the resource requirements listed in Table 6.9.

6.3.3.2 Disposal Site More Than 8 Kilometers From Plant Site

For this scenario a gravity flow conveyance system cannot be assumed. It was assumed, therefore, that the waste would be pumped from the plant to the disposal site. The system would consist of the following: a pump station located at the plant; a pipeline from the pump station to the crest of the tailings retention dike where slurry waste would be discharged directly into the holding ponds, and booster pump stations as required. The system would be very similar to that described previously for transporting slurry ore from the port to the plant except that a slightly larger diameter pipeline, or slightly higher transport velocity, would be required for the higher throughput.

Resource requirements, potential environmental impacts, safety aspects, etc. are identical to the slurry ore transport system previously discussed in Section 4.0.

6.3.4 Method of Operation of a Tailings Disposal System

As stated before, the process wastes would be transported to the tailings disposal area in a slurry pipeline. If necessary a pump station would be installed at the disposal site to distribute the slurried tailings through distribution pipes and spigots, to the disposal area.

A decant system probably would be included in a tailings disposal facility to collect excess transport water or storm inflows and recycle this contaminated water to the process plant. The amount of water which would be available for decanting is a highly variable quantity dependent on several factors. The main factors are as follows:

1) the amount of water which is retained by the tailings

2) The rate of seepage out of the disposal facility and into the seepage interceptor system

3) The rate of evaporation

4) The amount of transport water,

5) The amount of storm water entering the system.

Probably the most variable factor is the rate of evaporation. In some arid areas the evaporation rate could exceed the net water inflows so little or no water would be available for decanting. If the facility were located in a region of high precipitation with a smaller net evaporation, more water would be available for recycle back to the plant. It has been assumed that approximately 20 percent of the slurry transport water would be decanted and pumped back to the process plant. The actual amount is dependent on site and process specific conditions.

A summary of the major components required in a tailings disposal system as assumed for this study are summarized in Table 6.8. Conservative assumptions were made regarding the distribution and spigot system. As a result, relatively large quantities of discharge pipe are listed in Table 6.8 and correspondingly high power requirements are listed. Under favorable conditions both of these factors could be reduced by as much as 50 percent or more.

TABLE 6.8

STRUCTURAL AND MECHANICAL REQUIREMENTS FOR
TAILINGS DISPOSAL SYSTEM

Item	3-Metal Plant	4-Metal Plant
Embankment m^3 (yds^3) x 10^6	10 (13)	4.3 (5.6)
Slurry Discharge Equipment		
Centrifugal pumps kw (HP)	600 (800)	49 (65)
Distribution pipe length/diameter	3200 m/25 cm (10,500 ft/10 in.)	700 m/15 cm (2300 ft/6 in.)
Lining material, hectares/year (acres/year)	36 (90)	7.2 (18)
Decant system		
Centrifugal pump kw (HP)	60 (80)	4.5 (6)
Return pipe length/diameter	1830 m/10 cm (600 ft/4 in.)	370 m/7.5 cm (1200 ft/3 in.)

6.35 Reclamation

Reclamation of the tailings disposal facility implies two aspects. The first is stabilization of the top layer of tailings so that they are not susceptible to wind erosion. The second is establishment of a vegetative cover over the disposal area. The first step can be accomplished by covering tailings with a material which is not susceptible to wind erosion, such as a coarse sand or gravel material, or by chemical stabilization. If a substantial portion of the tailings are hydrous slimes, physical stabilization could be difficult. This is because the slimes may never ever reach a consistency where equipment could be operated directly on the slimes. Chemical stabilization of the surface of the slimes is feasible, but normally is not considered to be a permanent solution. During the active life of the pond the water surface could be regulated to keep most, if not all, the surface wet. This is difficult in dry climates but can be accomplished if the pond area and decant system is sized and operated effectively.

The more difficult aspect of reclamation would be establishing a vegetative cover over the tailings disposal facility. Although the slopes of the embankments could be vegetated, it may be difficult to place topsoil on the slimes for the same reason as it is difficult to physically stabilize the slimes surface. Based on the character of the hydrous slime tailings, it is assumed that they would not support vegetation. Therefore it may not be possible to revegetate the surface of the reservoirs. Also because of the consistency of the tailings, the disposal area may never be suitable for alternative uses such as a light industrial development. However, it is also quite possible that tailings will be predominantly settleable sludge which would dry and compact naturally and therefore not present stabilization and revegetation problems.

6.3.6 System Resource Requirements

To quantitatively evaluate the support requirements for a tailings disposal system it was necessary to make many assumptions regarding how the facility would be constructed. The assumptions made provide values for conservative operating conditions on relatively flat disposal sites. Substantial variations could occur depending on the actual conditions at a given site. The resource requirements for this system are summarized in Table 6.9.

We assumed that the tailings would be in a slurry form with an in-place dry density of 800 kgs/cubic meter (50 pounds per cubic foot) and that they would be placed to a depth of 12.2 meters (40 feet). Manpower needs were based on the requirements for similar-sized operations; continual monitoring of the system will be required to insure that the tailings distribution system is functioning properly and that the monitor wells are periodically observed.

The energy requirements are based on the assumption that tailings disposal would in a relatively flat area; therefore, containment dikes would be needed on all four sides of the tailings disposal facility. Higher rates of energy consumption would be obtained if the tailings had to be pumped uphill; and lower rates would be obtained if the tailings could be distributed with a gravity system.

TABLE 6.9

SUPPORT REQUIREMENTS FOR TAILINGS DISPOSAL SYSTEM

Item	3-Metal Process Plant		4-Metal Process Plant	
Land, hectares/yr (acres/yr)	40	(100)	7.2	(18)
Manpower, manshifts/day	4		3	
Gasoline, m^3/yr (gallons/yr)	53	(14,000)	27	(7,000)
Diesel, m^3/yr (gallons/yr)	240	(63,000)	95	(25,000)
Electricity, kilowatts	660		55	
Water, m^3/yr (gallons/yr)	Negligible		Negligible	
Cover material (topsoil), m^3/yr (yd^3/yr)	123,000	(160,000)	23,000	(30,000)

The energy requirements include the average annual fuel consumption for constructing the tailings embankments. In all probability, the construction of the embankments would be contracted and done only periodically throughout the life of the project. However, for purposes of this study, the overall construction requirements were divided by the life of the project so that an annual energy consumption was obtained.

6.4 OCEAN DISPOSAL

Ocean dumping of process wastes has been described in detail in Chapter 3.0. Therefore, only a summary is provided in this section of the report.

6.4.1 Land Transport of Waste

The pump station and pipeline required to transport the tailings from the plant to the port will be very similar to the system previously described in Chapter 4.0 for transporting slurry ore from the port to the plant except that a slightly larger diameter pipeline or slightly higher transport velocity will be required for the higher throughport. Using the same type and size of equipment will lead to economies of scale. Resource requirements and equipment discriptions are identical to the slurry ore transport system previously discuused in Chapter 4.0.

6.3.2 Equipment Required

The most likely disposal ship would be the transport ship used for bringing nodules ashore. No additional pumping capacity would be needed, nor vessel steaming distance, and the discharge could be made in route to or near the original nodule dredging site.

The pumping equipment for the slurry ships would be as described for the nodule ships in Section 3.2.4.1. The deep water discharge pipe would probably be 15 to 30 cm (6 to 12 iches) in diameter, segmented for rapid connect and disconnect, and lowered by crane and winches at sea. Although this is a unique operation, many methods could be developed to perform the discharge and pipeline recovery safely.

6.4.3 Disposal System Resource Requirements

The ocean disposal of waste tailings would require facilities at the marine loading terminal, new or larger ships or barges, and some small labor, fuel, and maintenance inputs. The marine terminal for the ship would have to be large enough to store at least one week's volume of waste, and would probably include transport water tanks, slurry ponds, pump station, pipeline access to and from the process plant, electrical power in moderate amounts, and road access. The nodule and waste slurry ship terminal is described elsewhere in detail in Section 3.3.1. The water for the slurry would be regarded as transport water, or simply taken from the sea.

No new facilities or labor would be required to service these vessels. Labor to man the vessels and marine terminal is readily available.

6.4.4 Legal Concerns

It should be noted that it would probably be necessary to obtain an EPA permit, which is reviewed by EPA as well as other Federal agencies (including NOAA), to engage in an ocean dumping operation. In order to qualify, the applicant would have to demonstrate that there would be no deleterious effects on the marine environment.

7.0 REFERENCES

Brobst, W.A., 1972, The Probability of Transportation Accidents. U.S. Atomic Energy Commission.

Bureau of National Affairs, 1974, Clean Air Act, in Environment Reporter. Federal laws, p. 71:1101-71:1127.

Bureau of National Affairs, 1975, Safe Drinking Water Act, in Environment Reporter. Federal laws, p. 71:6041-71:6051, Bureau of National Affairs, Washington, D.C.

Bureau of National Affairs, 1976, Resource Conservation and Recovery Act, in Environment Reporter. Federal laws, p. 71:3101-71:3116, Bureau of National Affairs, Washington, D.C.

Bureau of National Affairs, 1977, Federal Water Pollution Control Act, in Environment Report. Federal laws, p. 71:5101-71:5131, Bureau of National Affairs, Washington, D.C.

Corps of Engineers, Department of Army, June, 1973, West Coast Deepwater Port Facilities Study. C of E, San Francisco, 7 vol.

Dean, K.C. and Shirts, M.B., 1975, Vegetation Techniques for Acidic and Alkaline Tailings. Paper presented at the "Disturbed Land Reclamation and Use in the Southwest", Short Course, University of Arizona, Tucson, Arizona, Jan. 1975. (Also available from the USBM, Salt Lake City, Utah)

Douglas, T.B., Economics of 5 1/2 Mile Transport Conveyor Belt at Ideal Cement Company's ADA, Oklahoma Plant. Society of Mining Engineers of AIME, Paper 61HK28.

Environmental Protection Agency, 1975a, Ore Mining and Dressing Point Source Category; Interim Effluent Limitations and Guidelines, and Proposed Pretreatment Standards. Federal Register, v. 40, n. 215, p. 51722-51748.

Environmental Protection Agency, 1975b, Hazardous Substances, Designation, Removability, Harmful Quantities, Penalty Rates. Federal Register, v. 40, n. 250, p. 59960-60017.

Environmental Protection Agency, 1976, Grants for State Underground Water Source Protection Programs; State Underground Injection Control Program, Proposed Regulations. Federal Register, v. 41, n. 170, p. 36726-36745.

Ferriter, Bob and Figimoto, Bob, 1977, Mining Enforcement and Safety Administration. Mine Waste Branch, Denver, Colorado, personal communication, January 28, 1977.

Hall, J., and Reynolds, T.D., September 1974, Ocean Disposal and Liquid Chemical Wastes. Texas A&M University, Marine Technology Society.

Harker, H., Piskura, J., Roy F. Weston Assoc., F. Cross & Richer, Orba Corp, 1974, Environmental Impact Assessment for a Marine Bulk Transfer System. International Association for Pollution Control, Washington, D.C.

Kirshenbaum, Noel W., Wise, Theodore R., Jr., Marcona Corp., February 1974, Determinants in Selecting Slurry Versus Conventional Shipping Systems. American Institute of Mining, Metallogical and Petroleum Engineers.

Klohn, E.J. and C.H. Maartman, 1973, Construction of Sound Tailings Dams by Cycloning and Spigotting. Tailings Disposal Today, Proceeding of the First International Tailings Symposium, Tucson, Arizona, Miller Freeman Publications, Inc., 1973, pp. 232-267.

Kray, C.J., 1973, Design of Ship Channels Maneuvering Areas. American Society Civil Engineers - 1973 February, #9559.

Malone, V.F., December, 1964, A Study of Long Distance Haulage. Mining Congress Journal, p. 25-29.

Marconaflo, Inc., May 31, 1976, Application of Slurry Technology to the Maritime Industry. Maritime Administration.

Maritime Administration, Division of Ports, Department of Commerce, 1972, The Economics of Deepwater Terminals.

Maritime Admininstration, Western Region, Department of Commerce, June 1976, Untangling Dredging Regulations.

McElvain, R.E., Cave, I., 1972, Transportation of Tailings. Proceedings First International Tailings Symposium.

MESA, 1976, Design Guidelines for Mine Waste Piles and Tailings Dams. February 13, 1976, available from MESA, Technical Support Center, Denver Federal Center, Denver, Colorado.

Pfleider, E.P., et al, 1968, Surface Mining.

Rosenblatt, M. & Sons, Inc., August 1976, Shallow Draft Bulk Carrier. Maritime Administration, Department of Commerce.

Rouse, Jim, 1977, Environmental Protection Agency, Denver, personal communication, January 28, 1977.

Shirts, M.B. and Bilbrey, Jr., J.H., 1976, Stabilization Methods for the Reclamation of Tailings Ponds. Paper presented at the seminar, "Landscaping and Land Use Planning as Related to Mining Operations", Australian Institute of Mining and Metallurgy, Adelaide, Australia, March 1976. (Also available from the USBM, Salt Lake City, Utah).

Smith, D.D., and Brown, R.P., 1971, Ocean Disposal of Barge - Delivered Liquid and Solid Wastes from U.S. Coastal Cities. Dillingham Corp., La Jolla, California.

Swaisgood, J.R. and Toland G.C., 1973, Control of Water in Structures. Dames & Moore, Engineering Bulletin 41, Los Angeles, California, pp. 17-28.

Swan, David A., January 1974, The Potential of Manganese Nodules as a Future Mineral Resource. University of Washington, Seattle, Marine Technology, Society of Naval Architects and Marine Engineers.

Toland, G.C. and Versaw, R.E., 1976, Design of Impoundment and Evaporation Ponds and Embankments for Cyanide and Other Toxic Effluents. Transactions vol. 260, Society of Mining Engineers, AIME, March 1976, pp. 71-75.

U.S. Department of Transportation, 1970-1975, Accidents of Large Motor Carriers of Property.

U.S. Department of Transportation, 1969-74, Annual Summaries, 1969-74. Office of Pipeline Safety.

U.S. Federal Energy Administration, 1974, Project Independence Final Report.

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